THE ELECTRONIC BELT-FIT TEST DEVICE (eBTD): Activity update

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ABSTRACT

The single most effective automotive safety component that has been proven to save lives during a crash is a properly fitted seat belt. Transport Canada introduced the concept of assessing seatbelt fit for occupants in the early seventies. A Beltfit Test Device (BTD) was then developed to measure and assess this fit. Research was sponsored by Transport Canada to quantify the proper limits of certain scales on the device that are considered to represent proper beltfit.

To overcome the deviations of hardware tests and to allow evaluations of belt designs early in design phases, the Alliance of Automobile Manufacturers supported the development of a computer modeling and simulation approach, also known as the electronic Belt Fit Test Device (eBTD), through a Technical Working Group (TWG). That group includes representatives from the automobile manufacturers, Transport Canada and the software developer. The development takes place in close co-operation with the Joint Working Group – Abdominal Injury Reduction (JWG-AIR).

The computer model can be used at the design stage to assess the beltfit criteria developed using the BTD. This model can not only be used as a basis for verifying seat beltfit after the vehicle has been built, but can also be used as an effective design tool for restraint systems.

Recently, the development within the TWG has led to the signing of a Belt Fit Memorandum of Understanding (MOU) between Transport Canada and various automobile manufacturers. This

MOU represents the first collaborative effort between a government agency, the Alliance of Automobile Manufacturers and a software company, Human Solutions Inc., to develop an application that evaluates a safety concept, based on computer modeling and simulation in place of a physical measuring device. This paper describes this effort and highlights the results.

INTRODUCTION

The effectiveness of seat belts depends partly on the extent to which their geometric design matches the occupant's anatomical characteristics. Transport Canada determined that, in the past, the requirements of the Canadian Motor Vehicle Safety Standards (CMVSS) 208 and 210, which specify the permissible angle of the lap belt and stipulate the location of the upper anchorage of the shoulder belt, do not ensure that the lap and shoulder belts are positioned to provide the most benefit [3,4,5]. Accordingly, a physical Belt Fit Test Device (BTD) was developed by Transport Canada for the measurement and assessment of static seat belt geometry of automobile seat belts [6]. In essence, the BTD comprises an SAE H-Point Machine with the addition of special torso and lap forms that have been designed to represent a fiftieth percentile Canadian adult (both male and female). The surfaces of the lap and torso forms are marked with scales which facilitate the measurement of seat belt position. installed and belted on an automobile seat, the device enables lap and shoulder belt position to be read from the scales, for comparison to a specific belt-fit criterion.

Transport Canada has established four limiting criteria with respect to the clavicle, sternum and the outboard and inboard lap scales. Transport Canada believes that belts which meet these criteria should restrain the occupant in a crash, while inducing less serious and fewer injuries to soft tissue and organs from belt forces [7&8].

Although the original intention was to introduce new seat belt fit requirements as part of the 1997 CMVSS 208 amendment, the automotive industry requested that further research be conducted before its use was mandated.

A number of concerns relating to the use of the BTD were raised by the automotive industry. These related to the inherent variability and repeatability problems in positioning the physical device into a vehicle and then placing the lap and torso portions of the seat belt over the body shell to measure the scale contact points for the belt routing (as explained in chapter five of this document). The industry pointed out that these factors made the physical BTD device and its application impracticable and insufficiently objective for a CMVSS certification requirement and test procedure. In response to these concerns, Transport Canada, the Canadian Vehicle Manufacturers Association (CVMA) and the of International Automobile Manufacturers of Canada (AIAMC) agreed to participate in a joint working group (the JWG-AIR) to resolve these issues.

In response to the variability issues involved with the BTD as a physical measurement device, verification of the proposed BTD procedure using computer simulation was suggested as an alternative. Verification by computer simulation could eliminate differences between different test contractors and operators, to the benefit of both Transport Canada and the vehicle manufacturers. Additional benefits for both Transport Canada and vehicle manufacturers from computer modeling include expanded occupant size models and sensitivity analysis as well as reduced test and travel expenses.

To initiate work on a computer based BTD, Transport Canada funded Genicom, Inc. of Montreal to scan the BTD and develop a computer simulation of belt fit on the BTD.

Computer-Based (eBTD) Program Development

The initial program development effort focused on creating a valid digital representation of the physical device. The approach implemented three parallel spline curves drawn "taut" over the lap and torso shell surfaces of a digital representation of a manikin while connected to known belt anchor points. A frictionless surface was assumed so that the computed forces at each anchor point would pull the belt over the manikin.

Initial validation efforts compared software analyses output from specific landmarks to results from installation of the physical BTD in two vehicle seats. These promising results led to a follow-up validation comparing software results to installations in ten vehicles. Of the 40 measurements taken, 30 software simulation results were within 1 cm of actual data points measured with the physical BTD. Further, 36 of the 40 simulation results were in congruence with the physical criteria results of either pass/fail. The four incongruent results were appreciably close between the first electronic BTD and physical BTD.

The model demonstrated correlation between eBTD and the physical BTD, except where seats, buckles, etc. have deflected the belt from the path that the webbing would take from the anchorage to the BTD.

It was concluded that the seat belt algorithm needed to be refined to include more complex seat belt and restraint system designs (retractable belts, different belt hardware components, seat design elements, etc.). Some work was done to enhance the seat belt algorithm [increasing the number of cross-sections representing the torso and lap surfaces, including tensile force calculations at the end of each belt, allowing user input for seat pan angle, seat height, seat width, buckle hardware parameters, Seating Reference Point (SgRP) and H-point locations]. However, attempts to integrate the module completely into manufacturers' CAD seat belt design software environments were unsuccessful.

Although this initial effort was unsuccessful, the attempt showed promise for the possibility of developing such a software module.

Subsequently, members of the joint working group were asked to identify possible solutions.

In the fall of 1998, Tecmath of North America, Inc. (now Human Solutions of North America, Inc.) was invited to join the modeling efforts.

Work began immediately on an enhanced prototype version of a software module to include the latest CAD data representation of the H-point machine, the lap and torso surfaces, and user-defined inputs for the location of the H-point, heel point, seat back angle, upper outboard, lower inboard and lower outboard anchor points.

Significant program accomplishments

<u>Seat belt width</u> – A new method was proposed and implemented for simulating the true seat belt width. It was agreed that seat belt width was needed only at the points of interest, i.e., where the belt crosses the various scales. Thus, efforts were focused on simulating realistic seat belt width and curvature over the lap and torso forms that is due to anchor point location and anchor design kinematics at the clavicle, sternum and lap surface areas.

Anchor point kinematics – To model anchor point kinematics, joint working group members collectively agreed upon common types of seat belt anchors, buckles and retractors that represented approximately 95% of seat belt designs. These designs were then analyzed to determine the main parameters that could be used to mathematically model their motion behavior.

<u>Digital data for eBTD</u> – Discrepancies between existing and actual CAD data for the BTD were resolved. The original paper drawings for the BTD were obtained and compared to the current digital drawings. Corrections were made to the digital BTD CAD data to make the torso and lap forms symmetrical along a mid-sagittal line, incorporate the accurate H-point foot dimensions, and insert the appropriate modified seat and back pan dimensions into the model. These pans had originally been created when it was discovered that the original H-point pans interfered with seat belt routing over the lap and torso forms.

<u>Further refinements</u> – Other work performed to enhance the eBTD module included: refinement of the user-interface, increasing the software stability, determining proper measurements when the belt does not contact the surface, inboard lower anchor stiffness model, and inclusion of an error estimate.

Refining the user-interface -This entailed creating windows for accepting user input for the location of the eBTD, H-point, seat back angle, seat pan angle and heel point location. Additions were also made to ease data translation from CAD systems into the module via an Initial Graphics Exchange Specification (IGES) data translator.

Removing various self-limit checks from the original seat belt centerline calculation that were not applicable for the eBTD enhanced software stability. Additional stability was obtained after implementing the correct CAD data for the eBTD device and fine-tuning the algorithm used to calculate the spline curves for the centerline routing.

For instances where the simulated belt width did not come into contact with the torso or lap surface, at least at the measurement scales, methods were implemented to project a perpendicular line from the inner/outer detachment point to the scale. Thus, measures could still be obtained despite there being no contact.

BELT FIT METHODOLOGY

The belt routing calculation is based on three main components that represent beltfit simulation; they are anchor kinematics, the representation of the eBTD manikin, and the interaction, i.e. the contact of the belt with these two components. Once the belt routing calculation is determined, the scale values are computed according to the BTD deployment manual [9].

Basic Concept of Simulation

The belt routing simulation is based on several assumptions:

- The weight of the seat belt and anchorages is negligible compared to the tension forces.
- 2. The friction between the seat belt and other contact surfaces is negligible.
- The tension forces in the seat belt are much larger than inertia forces in the anchors.
- 4. Environmental considerations such as temperature etc, do not affect the outcome.

Hence the seat belt can be appropriately modeled by a massless object, which is not affected by

friction on the shells. The anchors can be modeled by flexible objects, which are driven completely by the belt and are not obstructed by the environment. Earlier versions of the software had taken into account frictional forces, but the results showed that the influence of the friction to the scale readouts is negligible. Therefore no friction is taken into account in the current version.

The essential concept of the belt routing simulation is to consider the seat belt as a wide. thin rubber band, which is fixed at its ends and is stretched across the eBTD surfaces, as shown in Figures 1 & 2. This rubber band is represented by a simple, dynamic, multi-body system consisting of particles connected with linear springs, called the spring network. Neglecting gravity, the simulation calculates the mechanical static force of equilibrium of the spring network subjected to certain constraints. The boundary conditions are the attachment of the network to the overall system with special anchors. Contact between the manikin CAD-Model of the BTD (eBTD) and the belt are also considered within the equilibrium conditions. Since the alignment, with respect to position and orientation of the anchors is not known in advance, the computation also provides corresponding anchor alignments.

Components of the Seat Belt Simulation

The entire belt simulation essentially consists of the three components:

- Spring network representing the seat belt
- Kinematic link chains representing the seat belt anchors
- CAD-Model of the BTD manikin
- These components are described in more detail in the subsequent sections.

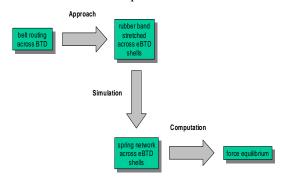


Figure 1: Basic concept of belt simulation

<u>Spring Network</u> – As shown in Figure 2, the seat belt is modeled by a network of massless particles connected by ideal massless linear springs, called the *spring network*. The network is structured as a matrix. The number of particles is calculated so that the longitudinal distance of neighboring particles is set to a default constant value.

An ideal linear spring is characterized by a default length, l_0 , and a spring constant, c. For the length, l, of a deflection and the induced spring

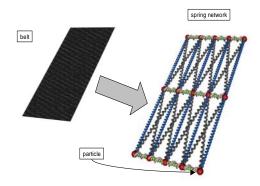


Figure 2: Representation of the seat belt band by a spring network

force, F, is given by

$$F = c(l - l_0).$$

These springs tend to cause a deflection of a length equal to its default length, l_0 . The amplitude of this deflection depends on the spring constant, c.

The particles are connected by four types of linear springs; namely; Longitudinal, Lateral (transversal), Long lateral and Diagonal, as shown in Figure 3.

The stiffness constants for these four types of springs are set so that the final calculated seat belt routing fits to the available experimental seat belt routing data and the computation of the force equilibrium equations for the network is achieved.

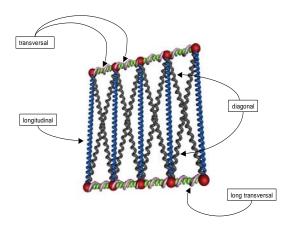


Figure 3: Different springs in the network

<u>Seat Belt Anchors</u> - All seat belt anchor kinematics are represented by kinematic link chains. These link chains are defined by the specification of link lengths and joint properties as degrees of freedom and ranges of motion. These kinematic chains are organized in classes. For each supported anchor class a corresponding link chain is implemented, which can be parameterized by values given by the user.

At the end of each link chain a corresponding seat belt edge is connected to the link chain. The length of this edge is equal to the seat belt width and a border particle row is uniformly fixed to this edge. In particular, particles cannot move across this edge. This means that in the case of the lower inboard anchor, particles do not move from the torso belt to the lap belt and vice versa during the simulation. The same is analogously valid for the upper outboard anchor with respect to the torso and retractor belt. The particles are distributed over the torso, lap and retractor belt in advance, so that approximately the same particle density (particle number per belt length) is achieved in the final belt routing. As an example see Figure 4 for the representation of the upper anchor. While all anchor kinematics can be completely parameterized via the graphical user interface, the lower inboard anchor, defined as anchor class B.2, plays an exceptional role. Unlike any other classes, this anchor possesses a continuous flexible part, which has no direct correspondence in a usual link chain. Hence this part is uniformly discrete and approximated by a fine link chain as shown in Figure 5. Those joints are equipped with one range of motion, whose

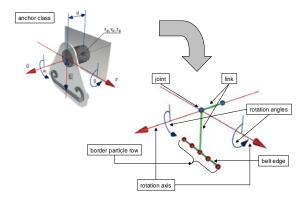


Figure 4: Representation of seat belt anchors

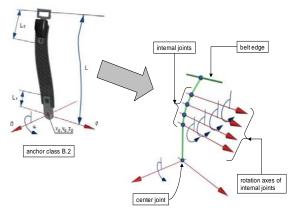


Figure 5: Representation of flexible anchor class parts

amplitude depends on the user specified stiffness parameter. This parameter ranges from soft to stiff to completely cover the full range of anchorage hardware from complete flexible to complete rigid.

CAD Representation of BTD - The CAD-Model of the BTD, was generated in two steps. First CAD surfaces for the torso and lap shell, based on original data from Biokinetics [2], were constructed. In addition, the SAE geometric and kinematic representation of the BTD frame was generated in CAD. As a second step, both surfaces were positioned with respect to the frame. For this procedure several measured fiducial points on the scales of the BTD shell were used to correctly adjust the shells to the frame as shown in Figure 6 & 7.

For the belt routing simulation, the torso and lap shell surfaces are approximated by triangle

surfaces. The density of this triangulation is determined by a compromise between simulation accuracy and computational performance

The above requirements dictate that the triangular surfaces will be an appropriate and smooth representation of the original shell surfaces.

The eBTD is assembled by positioning the overall CAD BTD frame with the shells attached to it. The position of the frame is defined by the following parameters derived from the BTD setup procedure [1]:

- 1. 3D-Coordinates of BTD H-Point
- 3D-Coordinates of right BTD Heel Point (ycoordinate automatically adjusted to eBTD dimensions)
- 3. Inclination of the BTD torso
- 4. The ankles of the eBTD are rigid.

Computation of Seat Belt Routing - As mentioned above, the final belt routing is simulated as a linear spring network subjected to static equilibrium. Since there is no closed form solution possible for the corresponding equilibrium equations, the solution of those equations has to be calculated numerically using an iterative approach. The nature of the iterative schemes is highly dependent on the initial configuration. Successive iterations of the configurations are calculated until a termination criterion is fulfilled.

Belt Initial Positioning - The method of determining the initial seat belt routing makes use of the position of the eBTD, in particular, of the torso and lap shells, and of the anchor definitions and locations. An initial seat belt routing is then calculated, which is a simple estimation not far from the expected final seat belt routing and runs outside the shell surfaces. Therefore, the initial shape of the seat belt routing is considered as a polygon of three pieces. The middle part of the polygon is determined by certain reference points fixed to the corresponding scales and is connected at its ends to the anchors in their default alignments except for the lower inboard anchor, which is automatically aligned to the middle part of the initial lap belt. The initial retractor belt routing runs linearly from the upper anchor to the car body fixation point. Figure 8 illustrates the initial seat belt routing for the torso and lap belt.



Figure 6: Fiducial points on BTD scales

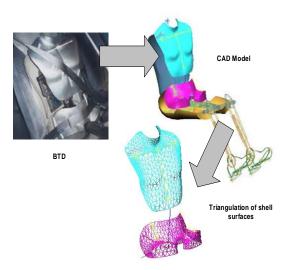


Figure 7: eBTD: CAD representation of BTD



Figure 8: Initial positioning of seat belt.

ITERATIVE APPROACH:

<u>Equilibrium conditions</u> - The calculation of the static mechanical equilibrium of the spring network primarily affects the position of the particles. Since the border particles are fixed to the link chains representing the anchors, the particle positions affect the alignment of the anchors.

<u>Rigid particle equilibrium</u> - In each iteration step, all current forces induced by the springs are calculated, in particular the total resulting force in each particle:

$$F_{\textit{result}} = F_{\textit{longitidud}} + F_{\textit{lateral}} + F_{\textit{longlaterd}} + F_{\textit{diagonal}}.$$

Depending on the total resulting forces, the particles are moved towards the static equilibrium configuration (Figure 9). This results in new positions where the resulting forces are smaller than in the current positions. There are no moments due to the structure of the spring network and therefore are not considered in the equilibrium equations.

Small resulting forces in all particles indicate that the equilibrium configuration is reached. Hence the termination criteria consist of checking the resulting forces and movement steps of the particles respectively against a given tolerance. The simulation process stops, when a given number of iteration steps is reached or termination criteria are fulfilled.

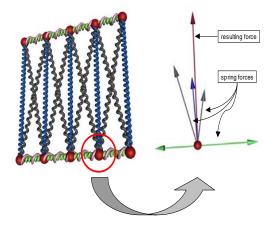


Figure 9: Movement of the belt representing particles

Anchorage simulation - The movement of the particles described above is free and unrestricted in space. But all border particles fixed to the anchors are subjected to the range of motions in conjunction with the link lengths of the kinematic chains modeling these anchors, i.e. they have to be located on the reach envelopes of the link chains. Hence the movement of these particles in space induced by the static mechanical equilibrium has to be transformed into joint rotations. This is done with moments that are induced in each joint by the spring forces in the border particles. Internal inertial forces of the anchors do not affect these moments. The moments are projected to the current rotation axes of the joint and transferred into joint rotation angles (see Figure 10). All rotation angles combined define the new alignment of the anchor, whereby these angles are restricted to the range of motion given by the user.

Small rotation angles in all joints indicate that the equilibrium configuration is reached. Hence the termination criteria consist of checking the rotation angles of the joints against a given tolerance. Moreover, these criteria are combined with the corresponding ones given above.

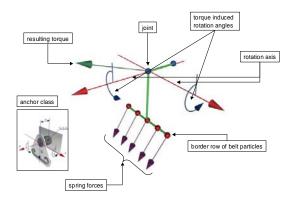


Figure 10: Rotation of anchor

<u>Contact between different components</u> - The movement of the belt is only restricted by the anchors. The torso and lap shells are considered by a separate contact algorithm between the particles and shell the surfaces.

The anchors are assumed not to be obstructed by environmental objects. Hence there is no contact control of the anchors except for the seat belt

edge, which is implicitly checked for all the particles in the vicinity of the edge surface.

<u>Contact check</u> - All particles of the spring network have either the status *free* (positioned free in space) or the status *contact* (positioned on a shell). At the beginning of the calculation all particles of the initial seat belt routing have the status *free*.

The movement for all *free* particles is calculated as explained above. Before the particles are moved to the new positions, the algorithm checks if particles would penetrate triangles of the shells. In that case the corresponding movement is restricted and the particle is placed on the intersection point on the shell and gets the status *contact*.

The movement for all *contact* particles is calculated as described below. Before the particles are moved to the new positions the algorithm checks if particles would leave the triangles of the shells. In that case the particle gets the status *free* again.

Figure 11 illustrates the movement of one particle, which changes from *free* to *contact* and back to *free* movement.

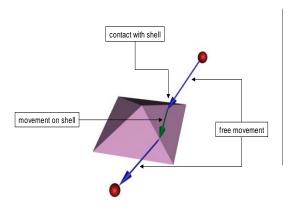


Figure 11: Particle movement relative to shell

Rigid particle Movement - As a particle is located on a shell, in particular on one triangle of the shell, the calculation of the movement is adapted to the new situation. In a first step the movement is determined and in a second step the resulting force is projected onto the triangle where the particle is located, if the force direction is to the inner side of the triangle and the shell

respectively. This projected force is assumed to be not affected by friction forces caused by the shells. Depending on this modified force the particle is moved towards the static mechanical equilibrium configuration. During a single iteration step a particle on a triangle moves at most to the border of the triangle, while longer steps are cut at the border. A simple example of a movement on a triangle is shown in Figure 12.

<u>Determination of Scale Values</u> - The scale values of the final belt routing are determined according to the BTD manual [8]. First all elements, comprising the eBTD with scales and the belt routing, is projected onto an xz-plane. Second, the relevant belt edges are intersected with the corresponding scales (torso belt: lower edge, lap belt: upper edge). Third, the scale readouts are determined (Figure 13). Moreover, the algorithm checks whether at least one edge of the seat belt band touches the scale of the scale readout. Using this information together with the pass/fail criteria, the algorithm provides the values of the scale readouts and indicates by green/red colors whether the pass/fail criteria are fulfilled. If no seat belt edge touches the scale, the corresponding scale readout is automatically marked by fail and no value is displayed.

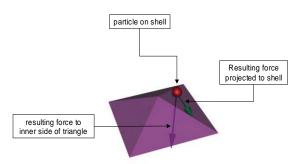


Figure 12: Projected force on shell

eBTD EVALUATION – The issue of variability of physical measurement is commonly known in all engineering endeavors that involves modeling and simulation of a physical quantity. The eBTD model is no exception. Verification and Validation (V&V) of such model has been an essential development objective of the software. A software developer performs software V&V to ensure code correctness, reliability and robustness.

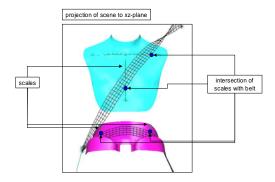


Figure 13: Determination of scale values

The objective of the eBTD model V&V is to ensure that the end product is a predictive model based on fundamental physics of the problem being solved.

eBTD VERIFICATION AND VALIDATION PROCESS

Since the eBTD is intended to be used as a simulation tool in the design process as well as a virtual certification tool, a V&V process is required to quantify the level of confidence in the predictions made with the models built using this software. The expected outcome of the V&V process is the ability to quantify the level of agreement between experimental and predicted results, as well as quantify the accuracy of the numerical models when used in a predictive mode.

The Verification and Validation definitions used in this report are adopted from [11] as follows:

- Verification is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution approach.
- Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

Verification and Validation are processes that collect evidence of a models correctness or accuracy for a specific set of parameters; thus, V&V cannot prove that a model is correct and accurate for all possible conditions and applications, but rather provide evidence that a model is sufficiently accurate. Therefore, V&V are ongoing activities that end when the desired sufficiency is reached.

Verification is concerned with identifying and removing errors in the model by comparing numerical solutions to analytical or highly accurate benchmark solutions.

Validation, on the other hand, is concerned with quantifying the accuracy of the model by comparing numerical solutions to experimental data.

Because modeling and/or mathematical errors can cancel, giving the impression of correctness (right answer for the wrong reason), verification must be performed before the validation activity begins.

Following the above logic, the software developer (Human Solutions Inc.) followed a mathematical based *verification* approach, to assure that the mathematical model perform as formulated. Therefore, it thought a Design Of Experiment (DOE) approach to take into account the effect of the greatest number of variables that affect the results. This approach enables the analysis to be carried out of the effects of different errors on the computations and as such, seeks to address as many sources of variability as possible. Since the determination of the error bounds is a mathematical objective of the eBTD model development, it was logical to rely on a DOE approach to assess these errors. Accordingly variability had to be dealt with as an outcome of the DOE approach. Human Solution's evaluation approach was designed such that the necessary input parameters were measured or deduced out of measurements in real vehicles. The idea behind this approach is to eliminate the manufacturing tolerances and to consider the real position of the eBTD in the vehicle of interest, i.e. the scenario is reconstructed in the simulation software exactly as it can be observed in reality. The resulting calculated scale values were compared with values taken from experiments with real vehicles of the corresponding make and model. From the available 34 data sets, 15 vehicles were considered for comparison. The mean differences for the individual belt fit scales using data corrected to match the position of the eBTD were in the range of -0.2 cm and -0.7 cm with corresponding standard deviations of 0.8 cm and 2.5 cm. With corrections to the anchorages, then the mean differences range from 0.1 cm and -0.3 cm with corresponding standard deviations of

0.3 cm depending on the specific interpretation of the tests [13].

The above verification effort was followed by a number of physical tests by Biokinetics [12] with the objective of validating the physical phenomenon. In these tests, it was necessary to follow an approach that seeks to reduce, and perhaps eliminate the sources of variability and errors. Biokinetics used design data as input parameters to run the belt routing simulations. Design data in this context corresponds to parameters that are measured or derived from CAD drawings. Vehicle manufacturers for the vehicles tested provided these data. The resulting calculated belt score values were then compared with values measured in experiments with real cars of the same make and model. The deviations between the measured and the calculated scales were in the range of -7.0 cm and 3.0 cm. While the discrepancies are large, a statistical test that compares the average deviation between measured and calculated scale values could not be conducted since the evaluation was based on four vehicles only.

These promising results led to a follow-up validation comparing software results to the physical BTD installations in vehicles. Thirteen passenger vehicles participated in a workshop to evaluate the use of the eBTD simulation module as an alternative to the physical measurement device. Simulations were completed for only 9 vehicles, due to lack of design data.

Differences were calculated between the score predicted by the eBTD (Design based) simulation and the score measured with the physical device. The absolute values of these differences are presented in Table 2. Each scale and vehicle is listed and for those vehicles for which the simulation was not completed, an n/a is recorded.

The average variation for each scale is computed and presented in **Table** 2. Previous work found that the expected maximum standard deviation from physical measurements is 0.6 cm (Anctil, 2001). This deviation is based on data from both lap and torso forms, several seat locations, a total of 10 samples per seat and a test matrix of vehicles.

Correlation Coefficients

Correlation coefficients were used to determine the relationship between two different sets of eBTD scores. The range of a correlation coefficient is 0 to 1, where 1 represents an exact correlation. The correlation coefficient is computed using the following equation:

$$\begin{split} \rho_{x,y} &= \frac{\operatorname{Cov}(X,Y)}{\sigma_x \sigma_y} - 1 \le \rho_{xy} \le 1 \\ \text{And:} \quad \operatorname{Cov}(X,Y) &= \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu_x)(y_i - \mu_y) \end{split}$$

Where : σ = standard deviation

and $\mu = \text{mean}$.

The correlation coefficients were computed to compare the BTD scores resulting from the physical measurements and several eBTD simulations. The results, presented in Table 3, include only the nine vehicles for which the simulations were successfully completed.

An additional scenario is included in which the effect of the B2 anchorage stiffness parameter is investigated.

Table 2 - Variation of eBTD and BTD Scores

Vehicle No.	Outboard (cm)	Lap, Inboard (cm)	Sternum (cm)	Clavicle (cm)
1	0.4	1.3	0.5	0.2
2	0.0	0.3	0.1	0.4
3	0.5	0.5	0.2	1.3
4	0.3	0.1	3.0	0.7
5	n/a	n/a	n/a	n/a
6	n/a	n/a	n/a	n/a
7	0.1	0.4	0.1	1.2
8	0.4	2.7	1.7	0.4
9	0.1	0.8	1.3	0.2
10	n/a	n/a	n/a	n/a
11	0.9	0.3	0.3	0.6
12	0.2	0.3	0.4	0.9
13	n/a	n/a	n/a	n/a
Average:	0.3	0.7	0.8	0.7

In this scenario, the design simulation was repeated using the measured stiffness for the four vehicles in which the design stiffness was considerably different from the measured stiffness.

The results show that the lap inboard score has a lower correlation in all scenarios. This score can be greatly affected by the anchorage stiffness. The means by which the stiffness parameter is measured or defined can highly affect the results. It is shown that the correlation improves between the design simulation and the measured scores when the measured stiffness parameter is used (scenario 4).

Another reason that the lap inboard score is not expected to correlate well between simulations and physical measurements has to do with the thickness of the buckle.

Table 3 - Correlation Coefficients for BTD Scores

		Lap Outboard	Lap Inboard	Sternum	Clavicle
1	Design Simulation vs. Physical BTD	0.78	0.39	0.81	0.87
2 .	Measured Simulation vs. Physical BTD	0.83	0.48	0.92	0.91
3 .	Design vs. Measured Simulations	0.62	0.20	0.88	0.91
	Design (modified) vs. Physical BTD	0.84	0.53	0.86	0.79

Currently, the simulation does not take the thickness into account and, if the buckle is resting against the seat or the physical BTD, the detachment points of the belt with the buckle can differ between the simulation and the physical device

Pass/Fail Prediction

Perhaps more important than the score itself, is whether or not the simulations can predict the pass/fail outcome of the seatbelt fit based only on the design data. Considering the 9 vehicles for which both the BTD and eBTD scores are available, the eBTD predicted the same pass/fail outcome for the lap outboard in all cases. For the lap inboard, sternum and clavicle scores, the eBTD predicted 8 out of 9 pass/fail outcomes for each category correctly. Overall, that is 33 out of 36 (or 92%) correctly predicted outcomes.

It is known that the specified design stiffness for 4 vehicles is incorrect and considerably different from the measured stiffness. For vehicle 8, this difference is sufficient to change the pass/fail outcome. When these simulations are repeated using the design data for the geometry and the measured data for the stiffness, the eBTD predictions for vehicle 8 are the same as predicted by the physical BTD. This raises the eBTD prediction success rate from 92% to over 97%.

It should be noted however, that almost all of the scores recorded during this workshop were passing scores. To better evaluate the prediction success of the eBTD module, it would be desirable to have a larger representation from vehicles that would provide a failing BTD score.

Of the 40 measurements taken, 30 software simulation results were within 1 cm of actual data points. Furthermore, 36 of the 40 simulation results were in congruence with the physical criteria results of either pass/fail. The four incongruent results were appreciably close between the first electronic BTD and physical BTD. The eBTD simulations were able to predict the correct pass/fail result for 92% of the reported scores and the average difference between the scores ranged from 0.3 to 0.8 cm for the different scales.

The validation results demonstrated correlation between eBTD and the physical BTD, except where seats, buckles, etc. have deflected the belt from the path that the webbing would take from the anchorage to the BTD.

ENHANCEMENT OF SIMULATION – To enhance the current simulation further developments are underway. For example, an extension of the anchor kinematics library will enlarge the use of the simulation software by enabling the coverage of a higher number of scenarios. Here two principal approaches are conceivable: To incorporate the kinematic properties of existing anchors or to provide a

parametric approach that enables the user to define own anchorages.

In an early design phase the principal package of the occupant compartment is known but often not necessarily the details of the interior design that could possibly influence the belt routing significantly. Examples are the contours of the seat pan and the back rest in case a contact between the belt and the upholstery occurs. Consequently a generic seat with morphing functionalities to adapt to the seat is of great potential.

TRANSFER OF TECHNOLOGY ONTO **HUMAN MODELS** – Since the BTD represents one anthropometric type in one position benefits may result from transferring the described technology to human models representing occupants of different size and gender. Thus whole populations represented through manikins with different anthropometric properties in many postures can be analyzed. The belt routing can be assessed in a general sense, i.e. whether the belt lies too close to the neck or too close to the shoulder or even on the upper arm (Figure 14). Additional checks can be performed in the case where the human model represents a bony structure, i.e. the basis for the original BTD criteria, or where the belt stretches over the bony structures of the torso (Figure 15).

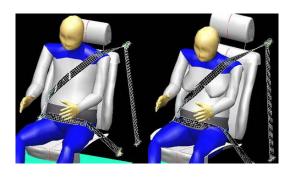


Figure 14: Belt routing for different RAMSIS

USAGE IN RELATED AREAS – There are many fields of application in which a realistic 3-dimensional model can be used. Besides testing an existing belt restraint package with given seat travel path and given anchor kinematics and applicable adjustments, the belt routing module

can be used to find optimal locations, types, and adjustments of anchors.



Figure 15: Belt routing and bony structure of RAMSIS

Secondly, it is conceivable to use the simulation results to provide a first estimate of the perceived comfort. Here, contact surface detachment points from the torso, and angles in which the belt leaves the human body could be used as input parameters for future simulation models.

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MASS-BASED CONSIDERATIONS FOR HEAD INJURY PROTECTION DEVELOPMENT

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ABSTRACT

The purpose of this research study is to understand the mass limits of typical instrument panel (IP) components given standard design guidelines for head injury risk reduction. The IP components of passenger vehicles are continually changing to increase features and quality. Consequently, these changes increase the mass of the IP components. It was hypothesized that, regardless of the mounting, certain IP components possess significant inertial resistance such that injury risk values may be above accepted risk levels without modification to their internal structures. Using the FMVSS201 test procedure, multiple IP components from several vehicles (n=6) were tested for head injury risk both in-vehicle and as isolated suspended systems. The isolated components were tested using a simple pendulum setup with the component properly oriented and suspended from 2m cables. component then was impacted with a 6.8kg linear head impactor at a velocity of 19.0km/h. Initial results showed that in an isolated state, the injury values, both peak and 3ms clip deceleration, correspond to as much as 93% of the in-vehicle tested values. From the component and in-vehicle tests, work functions based on the component mass were developed to replicate the impact event and establish mass-based thresholds. Models studied included waveforms comprised of haversine, half-sine, triangular, trapezoidal and square functions. A simple spring-mass model was also used to characterize the impact event. Initial assessment of the model showed the energy associated with an impact to a typical 4.5kg tuner assembly is great enough to potentially exceed the acceptable injury risk values according to regulations. Furthermore, Federal integrated structures such as air bag modules have a lower mass threshold due to their internal stiffness and interaction with the IP. Based on these thresholds, some design guidelines to improve the crush characteristics of structures such as tuners, HVAC controllers, and air bag modules are presented.

INTRODUCTION

Every year in the United States, over 60% of the nearly 40,000 fatalities and 50% of the 2.7 million reported injuries are a result of a front directional crash [1-World Bank]. In these crashes, there is a risk of an occupant's head striking the instrument panel.

In the United States (US), Federal Motor Vehicle Safety Standard (FMVSS) 201 imposes regulations aimed at limiting the rigidity of the instrument panel to provide head impact protection to occupants [2-FMVSS]. Similarly, in Europe (Economic Commission for Europe (ECE) 21.01), Japan (TRIAS34-1975), and Australia (Australian Design Rules (ADR) 21/00), requirements specify maximum injury levels for similar head impact events [3 – ECE, 4-TRIAS, 5- ADR].

All of the requirements specify an upper limit of 80g's for a 3ms continuous time clip. However, the impact speed of the 6.8kg headform varies from 19.0 to 24.1 km/h, depending on the market. The 3ms clip acceleration represents the typical injury assessment reference value (IARV) used for instrument panel impact testing.

Regardless of the specific test conditions and impact zones, the primary technique used to meet the interior impact requirements is to maintain sufficient clearance behind instrument panel components (e.g. tuner assemblies, HVAC controllers, etc.) to reduce head injuries. However, the increased mass of components creates a logical limit where the inertial resistance of a component is too great to overcome and still meet the prescribed injury thresholds. Therefore, these components must be developed to absorb energy internally as opposed to translation of the overall component.

This paper focuses on establishing mass-based thresholds to meet government regulations with conventionally mounted designs. If the thresholds are exceeded, then internally stroking designs must be used to meet the regulations. Specific design criteria are discussed to illustrate options for the construction of these designs.

METHODS

For this study, FMVSS 201 test procedures were used to study the mass-based implications of various components. The basic test parameters involve a 6.8kg headform impacting the IP surface at 19.0km/h. The impactor has a 'rigid' aluminum hemispherical construction with a 165mm diameter and is constrained either linearly or by a radial pendulum [2-FMVSS].



Figure 1. Typical configuration for a FMVSS 201 instrument panel head impact.

Head Injury Risk Assessment

The injury judgment criteria is a 3ms continuous clip of the headform deceleration. For this study, the focus was on the 3ms clip deceleration, but maximum acceleration and loading rates were also investigated. Manufacturers typically target a 20% lower than regulation value for safety margin. For this study, an industry accepted 3ms clip of 64g's was used to establish the mass-based threshold.

The concept of 3ms clip acceleration tolerance stems from the Wayne State Tolerance Curve first published in 1971. In this study head drop tests of forty cadaver subjects were conducted to develop what is now referred to as the Wayne State Tolerance Curve. The curve is a relationship of peak effective acceleration to time and the subsequent injury risk. The curve shows that the skull fracture tolerance of the human head has an inverse relationship between acceleration and time for injury risk. The human skull can sustain equally either a high-acceleration for a longer duration [6-Hodgson].

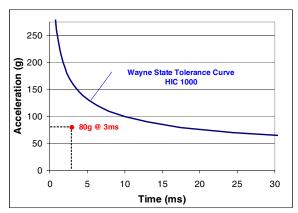


Figure 2: Wayne State Tolerance Curve depicting HIC1000 and the margin the 3ms, 80g IARV entails.

The 3ms clip IARV of 80g is clearly within the HIC1000 curve. Further, for a head contact event in which the head strikes the instrument panel, the time duration is typically below any range in which the HIC1000 tolerance curve would be exceeded.

Vehicle Testing of Tuner Assemblies

A variety of historical tests for impacts to the center of tuner assemblies were compared to establish an average jerk (g/ms) for a basic tuner construction design. Figure 3 shows that the average jerk for the tuner assemblies tested is 56g/ms. These tuners used conventional structures targeting a stroking unit mounted with deformable brackets. The mass of the tuner assemblies varied from 2.20 to 5.15kg.

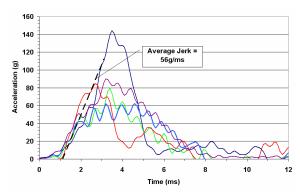


Figure 3. Acceleration versus time for a variety of tuner assembly impacts from various vehicles

Isolated Tuner Tests

A series of five impact tests were performed with the headform striking suspended tuner assemblies of various masses [Figure 4, 5]. The tuners were suspended from a 2m cable and impacted at a velocity of 19.0km/h with a 6.8kg headform impactor. The suspended tuners were impacted normal to the faceplate and in line with the center of gravity of the unit. The target point of the tuners corresponded (<10mm) with the geometric center of the faceplate. Headform acceleration was measured and processed according to SAE J211 [7-SAEJ211].

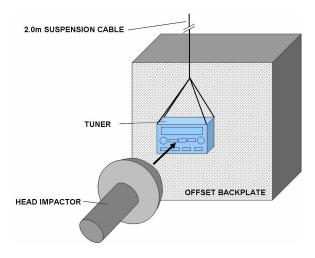


Figure 4. Setup of the isolated tuner test with the tuner suspended forward of a padded backplate to control the event after the initial impact.



Figure 5. Setup of isolated tuner test with the impactor loading through the center of gravity.

The tuners were also tested in-vehicle at the same relative angle and location. The comparison of component and in-vehicle tests showed linear correlation as high as 95%. Figure 6 shows one example comparing the in-vehicle test to isolated tuner test. This example illustrates a correlation of $(R^2 = 0.82)$ between the tests.

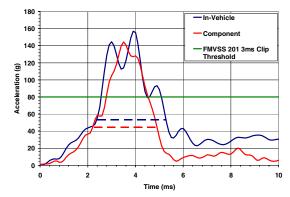


Figure 6. Overlay of tuner acceleration-time trace for the in-vehicle and component level impact test.

A review of the injury risk prediction values reveals that the isolated tuner assembly test represents a significant portion of the in-vehicle test. For the five tuners tested, the component test accounted for an average of 80% of the overall response measured in the vehicle test [Figure 7]. This suggests the tuner assembly inertia and stiffness account for the majority of the deceleration event, regardless of the in-vehicle mounting used for these particular conditions.

	3ms Clip (g)				Peak Accel (g)	
Tuner	Vehicle	Component	Percent	Vehicle	Component	Percent
1	53.4	44.7	84%	157.5	144.2	92%
2	45.6	36.2	79%	96.5	84.0	87%
3	45.6	42.5	93%	96.5	76.1	79%
4	66.1	52.6	80%	141.9	90.2	64%
5	35.3	23.2	66%	112.0	85.1	76%

Figure 7. Comparisons of 3ms clip and peak acceleration for in-vehicle and isolated component level tests.

Various Acceleration-Time Curve Waveforms

Based on the controlled input of the headform and mass of the impacted object, there exists a finite amount of energy available in the system. For this study, several waveforms were examined for their correlation to the measured performance of the head impact to tuner assembly. By examining these various models, it is possible to understand the upper and lower limits of what may be seen in actual vehicle testing. The waveforms studied included the following [Figure 8]:

- •**Square:** Perfect ideal response to impact (infinite jerk to a 3ms peak value). This form represents the maximum 3ms clip for a given energy input.
- •**Triangular:** Isosceles triangle response with ramp up/down rates equal to average onset from previous discussed vehicle tests.
- **Trapezoid:** Trapezoidal response with ramp up/down rate equal to the average jerk from vehicle tests and plateau 3ms in duration.
- Half Sine: Half period of sine wave with peak acceleration equal to that predicted by the component mass tests of the previous discussed tests.
- **Haversine:** Full period of shifted cosine wave with peak acceleration equal to that predicted by the component mass tests of the previous discussed tests.

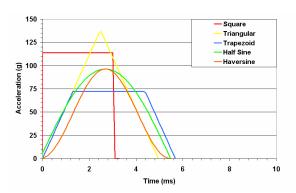


Figure 8: Various wave profiles for the energy transfer associated with a 4.0kg impacted mass given a 19.0km/h head impact.

For all the waveform profiles, the inputs by the headform remained constant for both mass and velocity. Further, the work done on the mass by the impactor was held constant for each mass, and the 3ms clip prediction subsequently calculated. Based on the mathematical models, the mass versus 3ms clip injury prediction was established [Figure 9]. The range of predictions for the various models was significant.

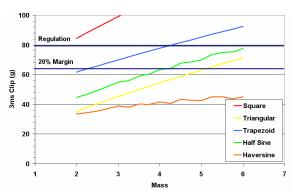


Figure 9: Relationship of component mass and 3ms clip acceleration for various wave profiles.

Dynamic Spring-Mass Model

A simple spring-mass model was used to establish the effects of varying the component mass given a constant input [Figure 10]. Given the input of a 6.8kg, 19.0 km/h headform, the mass of the component was varied from 2.0 to 6.0kg to establish a trend of mass versus injury risk. The spring stiffness was held constant and corresponded to the 56g/ms average jerk in the tuner impacts. In terms of stiffness, this is equivalent to 375N/mm.

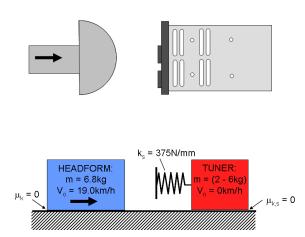


Figure 10. Spring-mass model used to relate the impacting headform to components of varying mass. The spring stiffness was held constant.

Using numerical integration, the dynamics of both the headform and tuner were calculated. Figure 11 shows the acceleration vs. time profiles of various component masses. From these time profiles, the subsequent injury risk potential (3ms clip) of the events for the various masses are presented [Figure 12]. For the mass range of interest, the injury risk prediction increases as the mass of the tuner is increased as originally hypothesized.

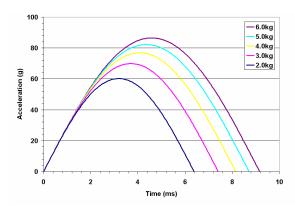


Figure 11. Predicted acceleration-time profile of various component masses.

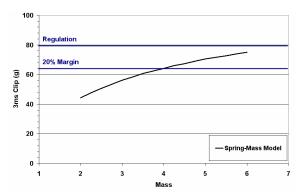


Figure 12. Injury predictive threshold of the spring-mass model used to relate the impacting headform to components of varying mass. The spring stiffness was held constant.

RESULTS / DISCUSSION

Correlation of Predictive Models

The comparison of the tuner impacts to the various waveform models showed the effectiveness of the models to both correlate the acceleration-time profile as well as the overall 3ms clip acceleration. For the five tuners studied, the haversine function correlated the strongest to the measured acceleration for actual tuner impacts [Figure 11]. The example shown in Figure 11 is for one of the 3.15kg tuner assemblies. The correlation varied dramatically between waveform models, but the haversine function had the highest correlation value ($R^2 = 0.93$) [Figure 12].

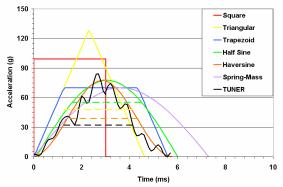


Figure 11: Acceleration-time relation of the waveform prediction models and the actual component tuner impact test.

Model	Correlation (R ²)	3ms Clip Error
Square	0.00	209%
Triangular	0.56	41%
Trapezoidal	0.65	103%
Half Sine	0.87	71%
Haversine	0.93	21%
Spring-Mass Model	0.42	75%

Figure 12: Correlation of the 3.15kg tuner impact to the various waveform prediction models and the error in 3ms clip prediction.

The predictive models and the actual in-vehicle tuner impacts were compared to establish the overall best predictors for the 3ms clip IARV [Figure 13]. The square wave and trapezoidal wave significantly over predicted the 3ms clip injury risk and can be disregarded as unrealistic. The triangular wave was the best model predictor to the in-vehicle tuner impacts in terms of 3ms clip prediction. Based on this model, a 5.0kg threshold is predicted as the mass at which there is inertial resistance to fail the IARV with 20% margin.

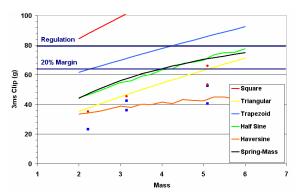


Figure 13: Correlation of tuner impacts compared to the predictive waveform models.

A slightly more conservative model compared to the triangular waveform would be either the half sine or spring-mass model. The mass threshold for these two models is 4.25kg given the 20% margin to the regulation.

Mass Based Threshold Predictions

Center Stack Components

A review of the predictive models used in this study show that the mass threshold of center stack components is between 4.25-5.0kg. This assumes a tuner assembly that is mounted to deformable brackets and the components can stroke into the instrument panel during impact At 4.0kg, the 3ms event is completed at 5.5ms according to the spring-

mass model, but the headform has displaced 11mm [Figure 14].

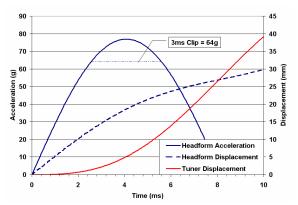


Figure 14: Relation of headform acceleration and displacement and the tuner displacement as a function of time.

As a conservative approach, the mass-based threshold for center stack components can be set as 4.5kg. Below this threshold, the ability to translate an instrument panel component is feasible given a representative stiffness, mounting structure, and clearance within the instrument panel to stroke. However, above this mass, the component must be designed with lower crush stiffness in order to internally displace and absorb the impact energy. At these higher masses, the injury risk portion of the event is over before the component strokes a significant amount.

Air Bag Modules

A similar investigation was carried out using impacts to the instrument panel over the passenger air bag module. Similar requirements exist for this area compared to tuner assemblies.

Typical designs by manufacturers involve either (1) crushable air bag module housings or (2) positioning the air bag below the instrument panel surface with sufficient stroke to absorb the impact before air bag module contact. With the latter design, a chute is applied to guide the air bag up and through the instrument panel surface.

To study the ability to translate the air bag module, CAE was conducted to measure the effects of the mounting brackets for a particular air bag assembly [Figure 15]. In this example, the air bag is mounted directly below the instrument panel surface and weighs 2.2kg. The brackets in the model were deleted to illustrate the inertia versus mounting effects of the system. The results for this study

showed, like the tuner, the air bag module's mass is responsible for the majority of the impact event [Figure 16]. The 3ms clip acceleration for the condition with the brackets removed was 93% of the normal construction with brackets attached. Similarly, the peak acceleration was 92% of the normal condition and the overall correlation was $R^2 = 0.95$.

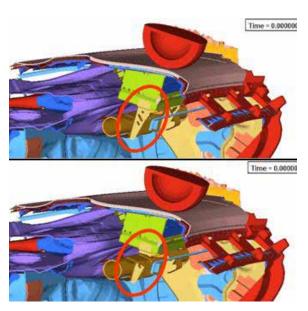


Figure 15: Instrument panel section showing the instrument panel as designed, and the brackets removed to compare the inertial and mounting effects.

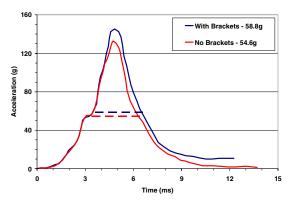


Figure 16: Comparison of the head impact to air bag module with and without mounting brackets.

By conducting an analysis similar to the center stack components predictive tool, a mass threshold of 2.5 kg can be set for airbag modules of comparable stiffness and mounting. The reduced mass threshold for the airbag module is a direct result of both the component stiffness and the interaction with IP

substrate, which engages more of the IP mass than the center stack components.

CONCLUSIONS

It was originally hypothesized that regardless of mounting, certain IP components possess significant inertial resistance such that injury risk values may be above accepted risk levels without modification to their typical internal structures. This study has confirmed this belief as well as established massbased thresholds for typical instrument panel components.

For tuners and other types of center stack components (e.g. HVAC controllers, NAVI screens, etc.), the predictive models show a limit at 4.5kg for maintaining a reasonable (20%) margin to the regulation. Above this level, the potential for excessive injury risk is high and the predictive model quickly elevates the 3ms clip estimation. For all the mass-based criteria, the mass of the tuner, brackets, and any other combine parts such as HVAC assemblies must be considered.

Alternatively, structures such as air bags which mesh with the overall IP surface and subsequently acquire more mass and stiffness from the surrounding structure have a considerably lower mass threshold of 2.5kg for the specific module analyzed.

Design Alternatives

The IP components of passenger vehicles are continually changed to increase features and quality, which consequently increases the mass of these components. While continuing to apply additional features and the subsequent mass, new approaches to complying with regulations are necessary. If the ability to remove mass or relocate components without compromising content is not feasible, alternative structures must be developed.

For tuner assemblies, if the mass exceeds 4.5kg, the tuner could be designed with reduced stiffness and compartmentalized into secondary components to avoid overall part translation.

Airbag modules typically can be designed to crush and absorb energy while still meeting deployment requirements. Due to packaging limitations, if the airbag module must be mounted directly beneath the IP skin or near the skin, the housing must be designed to absorb the impact energy in a controlled manner.

Using the aforementioned design techniques, functionality or quality does not need to be sacrificed to meet head impact requirements.

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SIMULTANEOUS EVALUATION OF MULTIPLE SAFETY FUNCTIONS IN PASSENGER VEHICLES

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ABSTRACT

Up to now quite a few electronic safety functions have been developed in order to successfully increase the safety of passenger in vehicles. Among them are electronic stability control (ESC), brake assists (BAS), lane departure warning systems (LDW) and so on. There exists a short literature on the quantification of the effectiveness of such safety systems on injury outcome or crash severity. As an example the ESC in several studies impressively has been shown to be efficient in avoiding a considerable amount of loss of control or skidding accidents. Nowadays many recently registered vehicles are equipped not only with one but instead with a number of safety functions (socalled safety equipment). The present paper proposes sound statistical methodology in order to investigate the safety benefit of such composite safety equipments (in contrast to a single safety function) in passenger vehicles. It seems obvious that the effectiveness of a specific safety equipment not simply is the additive superposition of the effectiveness of the safety functions of which it consists. For example one may be interested in the additional or incremental effect of an electronic stability control when a brake assist is already on board.

As well we consider secondary safety functions which do not aim at accident avoiding but at injury avoiding or mitigating. Therefore, methodology will be presented to evaluate injury mitigating effectiveness. On this basis it is possible to deal simultaneously with any combination of primary and secondary safety functions.

The developed methodology will be demonstrated on data examples. But the main focus lies on the presentation of methodology.

EFFECTIVENESS OF SINGLE SAFETY FUNCTIONS

For measuring the effectiveness of a safety function it is of critical importance to distinguish between different possible types of effects. In general there are at least four different types of safety function effects existent. These are:

- injury accident avoiding effectiveness
- injury avoiding effectiveness
- injury mitigating effectiveness
- effects of tertiary safety functions

Some safety functions aim at avoiding the accident at all, if this still is not possible anymore, it is tried to prevent any injuries of the involved persons. If this is not possible anymore as well it is tried to reduce the injury outcome as far as possible.

A typical primary safety function aims at all of these first three types of effectiveness, whereas the effectiveness of a typical secondary safety function only consists of the types injury avoiding and injury mitigating effectiveness. In some sense the first three mentioned types of safety function effects are hierarchically ordered. A safety function which aimed at accident avoiding may have some measurable effect on injury avoiding and injury mitigating in cases in which the accident could not be avoided but for example the crash severity has been reduced. A secondary safety function aiming for injury avoiding typically will have some effectiveness on injury mitigating but not on accident avoiding. Thus it becomes clear that a combined evaluation of different safety functions must be able to evaluate injury avoiding and mitigating effectiveness as well as the accident avoiding effectiveness separately.

Afterwards, i.e. after the accident has happened and the injuries are inflicted tertiary safety functions may come into action by calling the ambulance and doing other things to reduce the consequences of the injuries. In this paper we will focus on the first three types of effectiveness.

Even though, we will focus on the accident avoiding effectiveness for the next section.

RELATIVE RISK – ODDS-RATIOS

A reasonable way of measuring the effectiveness of a single safety function "SF" within a certain group of accidental situations "A" is to compute relative risks. For example an easy to interpret relative risk is the ratio of the probability that a vehicle with SF on board and active has to suffer an accident that belongs to A and the probability of suffering an accident belonging to A with SF not active. (cf. Equation 1).

$$RR = \frac{P(\text{suffering } A | \text{SF active})}{P(\text{suffering } A | \text{SF not active})}$$
(1)

As the relative risk is the ratio of two probabilities it can take any value in the interval $[0, \infty)$. If it equals one, the probability of suffering an accident of type A is independent of the safety function SF being active or not. If it is less than one, the safety function has some positive effect, if it is larger than one the effectiveness of SF is in the negative.

With simple algebra and Bayes law for conditional probabilities the equivalence between this relative risk and the following odds-ratio can be shown (Equation 2)

$$RR = OR = \frac{\frac{P(SF \text{ active} \mid A)}{P(SF \text{ not active} \mid A)}}{\frac{P(SF \text{ active} \mid N)}{P(SF \text{ not active} \mid N)}}$$
(2)

where *N* stands for a category of neutral accidental situations or for an internal control group of vehicle-related accidental situations. It is necessary that the relative risk of suffering an accident classified as *N* depending on SF active or not, must be equal or very close to one. This means that SF more or less has no influence on the probability of suffering an accident within the group *N*. For more detailed information on odds-ratios see Evans (1998), Kullgren et al. (1994), Hautzinger (2003), Kreiss et al. (2005).

It is important to point out the difference between accidents and vehicle-related accidental situations. There may be several vehicles involved in a single accident and the different drivers were most probably confronted with different situations that

led to the accident. So safety functions on board of vehicles involved in one and the same accident also are confronted with different situations. Therefore the effectiveness of a safety function on a specific accident highly depends on which of the involved vehicles is considered for the evaluation.

Thus, from now on when referring to a certain type of accident we are always talking about a vehicle-related classification of accidents.

For computing the term in equation (2) the two odds have to be estimated with the equipment-rates within the accident type of interest as it is shown in (Equation 3).

$$\frac{P(\text{SF active} \mid A)}{P(\text{SF not active} \mid A)} \approx \frac{\text{No. of cars with SF active within } A}{\text{No. of cars with SF not active within } A}$$

With this transformation we end up with a term that easily can be computed and is equivalent to the relative risk that easily may be interpreted, so that the effectiveness of SF within A can be computed as (Equation 4)

$$eff = 1 - OR$$
 (4)

The effectiveness then describes the percentage of avoidable accidents within the category A. To describe it more precisely:

Given that some vehicles are involved in critical accidental situations that in case SF is not active would lead to accidents of type A, then in *eff*·100% of the cases the accident could be avoided if SF would have been active.

Most safety functions do not have an influence on every accidental situation. In order to quantify the overall effectiveness of a safety function there are two possible approaches. Either the effectiveness within the subgroup of accidental situations which are sensitive to the safety function of interest has to be calculated and extrapolated to the complete set of accidents. Choosing A to be the category of "all accidents within the data-base" also leads to such an overall effectiveness. This second approach has the advantage that additional effects of the safety function on other than the selected sensitive accidents are not ignored. On the other hand it may be possible to include unwanted external variables in the overall effectiveness calculation. So for example if drivers of vehicles equipped with ESC typically have a parking assistant on board as well, then the calculated overall effectiveness of ESC would include some effectiveness on parking

accidents due to the correlation between ESC and parking assistants.

However the category N of neutral accidents for the second proposal will then be a subset of A. This does not lead to any problems within the calculation.

Classically type A is meant to be the type of accident which is influenced most by SF. But as for some studies a general effectiveness of a certain safety function is of greater interest we would like to point out this possibility of calculating the overall effectiveness of some safety function SF. Even though one has to keep in mind, that this effectiveness will be way less significant than some effectiveness concerning only a certain single accident type.

DATA EXAMPLE (1)

For a better understanding a short data example is presented in this section. Let us assume that our aim is to evaluate the overall effectiveness of each of two safety functions SF1 and SF2. So in both cases the accident type of interest *A* is any accident within a fictional data-base, where the information of the equipment with the safety function of interest is at hand.

As it is explained in the section above the first step is to characterize a type of neutral accidental situations for each safety function. The group of neutral accidental situations concerning safety function SF1 is labelled N_I and the other one accordingly N_2 .

Within our fictive data-base we find for 4632 vehicles the information whether or not they are equipped with SF1 and for 3354 vehicles whether or not they are equipped with SF2. For the calculation of the odds-ratio we simply need to count the number of cases within the following 2x2-contingency-table.

Table 1 Cross-tabular for calculating the odds-ratio

Cross-tabular for calculating the odds-ratio				
all vehicles where SF1		type of accident		
equipment is known		N_{I}	A	
SF1	Yes	56	641	
361	No	328	3991	
Sum		384	4632	

With this data the overall effectiveness of SF1 may be calculated with the formulas from equation (2), (3) and (4) which are combined in (Equation 5):

$$eff(A) = 1 - \frac{\frac{\text{No. of cars with SF1 within } A}{\text{No. of cars with SF1 within } N}}{\frac{\text{No. of cars with SF1 within } N}{\text{No. of cars without SF1 within } N}}$$

So we obtain the effectiveness of SF1 within A, that is the overall effectiveness by (Equation 6)

$$eff(A) = 1 - \frac{641}{3991} / \frac{56}{328} \approx 5.93\%$$
 (6)

Remember at this point, that we calculated the effectiveness of SF1 to any given accident and not only within the types of accidents, where SF1 is supposed to have the largest effectiveness which typically is much higher than this calculated 6%.

Similarly we calculate the effectiveness of SF2 by counting the number of cases from the following 2x2-table.

Table 2
Cross-tabular for calculating the odds-ratio

all vehicles where SF2		type of accident		
equipment is known		N_2	\boldsymbol{A}	
SF2	Yes	30	300	
312	no	279	3054	
sum		309	3354	

Using a similar formula as in equation (5) we obtain the overall effectiveness of SF2 in (Equation 7):

$$eff(A) = 1 - \frac{300}{3054} / \frac{30}{279} \approx 8.64\%$$
 (7)

So far we did not take into account any external variables that may have an influence, such as driver's age, surrounding conditions etc. See subsection "logistic regression and [...]" for more information on that.

EVALUATING MULTIPLE SAFETY FUNCTIONS

Of course it is of major interest to be not only able to evaluate a single safety function but as well a whole package of multiple safety functions. Oddsratios offer a well interpretable way of comparing any two (or even more) different safety equipments. In the above formula (Equation 2) the odds-ratio is calculated by somehow comparing the probabilities of suffering a certain accident given a safety function SF is active or not active. The very same approach may be applied if not looking at a single active or not active safety function but instead at some safety configurations. A safety configuration is considered to be a set of different safety functions such as "any car that is equipped

with anti-lock braking system, airbags and emergency brake assistant but does not contain ESC". So in our understanding a safety configuration means that certain safety functions are always included, certain safety functions may be excluded and no information on other safety functions are of interest. Let us assume that we intend to compare the effectiveness of some safety configuration SC I with the effectiveness of some safety configuration SC II.

The effectiveness calculated via the odds-ratio then describes the additional gain of safety of SC I compared to equipment SC II. Described in the words as above: Given that some vehicles equipped with SC I are involved in critical accidental situations that would lead to accidents of type *A*, then the question is, how many of these accidents could have been avoided if instead of SC I the safety configuration SC II would have been on board.

Of course SC I and SC II do not have to be a single specific safety configuration but as well may each describe classes of safety configurations. For example SC II may stand for "any safety-configuration that includes the safety function SF1 but excludes SF2" and SC I could be "any safety configuration that includes SF1 as well as SF2". For the sake of an easier interpretation of the results SC I should always include every single safety function that is included in SC II plus some additional safety function(s).

Let us come back to the example above. The corresponding effectiveness (Equation 8)

$$eff = 1 - OR = 1 - \frac{\frac{P(SC I|A)}{P(SC I|A)}}{\frac{P(SC I|N)}{P(SC I|N)}}$$
(8)

then describes the additional gain of SF2 within accident type A, given that SF1 is already existent.

Crucial at this point is the neutral accident type *N*. This type of accident has to be independent on **every** safety function that distinguishes SC I from SC II on its own!

For more detailed information on what we call multi-dimensional odds-ratios see Kreiss et al. (2006). Especially we want to stress the fact that it is not possible in general to calculate confidence intervals for odds-ratios of multiple safety functions.

DATA EXAMPLE (2)

Staying at the evaluation of SF1 and SF2 within our fictive data sample, we now want to investigate the interactions of the two safety functions. Recall that the effectiveness of SF1 was 5.93% and the effectiveness of SF2 was 8.64%. When analysing the interactions of the two safety functions we again need a group of neutral types of accidental situations. As we already identified some neutral types of accidents for each safety function, e.g. we obtain one possible group of neutral types of accidents concerning both safety functions by using the intersection of N_1 and N_2 . Let us assume we obtain the following 2x2-table.

Table 3
Cross-tabular for calculating the odds-ratio

Cross two trains for the contracting the courts rated				
all vehicles within data-		type of accident		
base, where SF1 and SF2 equipment is known		$N_1 \cap N_2$	A	
SF1 & SF2	Both	18	176	
None None		239	2612	
Sum		257	2788	

This leads to the effectiveness of having both SF1 and SF2 instead of none of these as it is calculated in (Equation 9):

$$eff(A) = 1 - \frac{176}{2612} / \frac{18}{239} \approx 10.53\%$$
 (9)

So the effectiveness of both safety functions is less than the sum of the two single safety function's effectiveness. Obviously there exists some interaction of the two safety functions.

Now we want to find out more details about these interactions. Table (4) helps us to evaluate the effectiveness of SF1, given that SF2 is already present. As the group of neutral types of accidental situations we may take the whole group N_I and not only the intersection of N_I and N_2 because all vehicles of interest are equipped with SF2.

Table 4
Cross-tabular for calculating the odds-ratio

cross tabalar for calculating the odds ratio				
all vehicles, equipped with		type of accident		
SF2, where SF1 equipment is known		N_1	A	
SF1	yes	18	176	
no		11	108	
sum		29	284	

So the effectiveness of SF1, given that SF2 is already on board of the vehicle is: (Equation 10)

$$eff(A) = 1 - \frac{176}{108} / \frac{18}{11} \approx 0.41\%$$
 (10)

This result may very well be interpreted as given that the vehicle of interest is already equipped with SF2, there is more or less no additional gain of SF1.

Remember again, that we calculated the overall effectiveness for all the accidents within the database. So there may exist a small group of accidents, where the effectiveness of SF1 given SF2 is much larger. But then necessarily this group of accidents has to be comparatively small as the overall effectiveness is so close to zero. As well we want to point out, that the number of cases considerably decreased in comparison to Table (1) and (2). This is due to the fact we not only need the knowledge whether a vehicle is equipped with SF2 or not but rather we need cases where the vehicle indeed *is* equipped with SF2. This effect typically occurs when working with real world accident data.

The other way around we now want to calculate the effectiveness of SF2, given that SF1 is already existent. Accordingly to Table (4) as all vehicles of interest are equipped with SF1, N_2 may be considered to be a group of neutral accidental situations. Let us assume that we obtain from our data-base the following table.

Table 5
Cross-tabular for calculating the odds-ratio

all vehicles, equipped with		type of accident	
SF1, where SF2 equipment is known		N_2	A
SF2	Yes	18	176
No No		29	328
Sum		47	504

Again the same calculation leads to (Equation 11):

$$eff(A) = 1 - \frac{176}{328} / \frac{18}{29} \approx 13.55\%$$
 (11)

Now the situation is completely different. We obtain a rather high overall effectiveness of SF2, given that SF1 already is existent.

To sum it up: With an effectiveness of 5.9% and 8.6% we observe a moderate effectiveness of SF1 and SF2, considered as single safety functions. The combination of both safety functions shows with an effectiveness of 10.5% that this effectiveness is less than the sum of the single ones, but still larger than the effectiveness of only one of them. By evaluating the interactions we found out that: SF2 is even more effective if SF1 is already existent (13.6%), whereas if SF2 is already existent it does not change much if SF1 is existent as well (0.4%).

Again it is important to point out that for all calculations any external influences were ignored.

We may not exclude the possibility that some of the computed results may be explained by some external variable(s). See subsection "logistic regression and [...]" for more information on this.

EVALUATING INJURY MITIGATING AND INJURY AVOIDING EFFECTIVENESS

So far odds-ratios have only been used for evaluating the accident avoiding effectiveness, but as pointed out in the beginning of the paper the other types of effectiveness (e.g. injury avoiding and in jury mitigating) are of major interest as well. Typically these types of effectiveness can be quantified on the basis of in-depth accident studies and simulations based on accident-reconstructions. But as we intended to propose a general approach that as far as possible is independent on the type of safety function of interest, we will present such an approach in the following. This approach will only lead to lower and upper bounds of the wanted quantities.

As seen in the section above, odds-ratios are able to evaluate the accident avoiding effectiveness of some safety configurations within a certain type of accident situations called A. To evaluate the effectiveness of a safety function on different severity levels of injuries, A has to be split up in ndifferent subgroups, enumerated according to an increasing severity of the accident. Thus A1 stands for all accidents within category A with material damage only, A2 may stand for all accidents within category A with slightly injured passengers only, up to An which stands for accidents of category A and with fatally injured passengers. As the described classification of the accidents is vehicle-related. only the occupants of the vehicle of interest are relevant for the classification Ax, x=1,...,n, and not for example the most severely injured person involved in an accident.

Assume a crash of type A would lead for a vehicle not equipped with a certain safety function to a classification of Ax. If the vehicle would have been equipped with this safety function the accident outcome would only be of type Ay with some y < x. This is a typical case of injury mitigation. Thus, every injury mitigation will appear somehow as accident avoidance within a certain subgroup. Therefore the so far developed methodology can be applied in principle.

If in the above situation y = 1 it is not only injury mitigation but injury avoidance, so injury avoidance may be handled similar to injury mitigation. As well it may be possible that an accident without injured persons involved is not reported in the data-base at hand anymore. In this case injury avoidance appears as accident

avoidance. This means that if we are able to properly deal with accident avoiding and injury mitigating effectiveness, then we implicitly have covered injury avoiding effectiveness.

We would like to point out that injury mitigating in general does not change the total number of accidents within the data-base. It just leads to a different distribution over the considered categories of accident severity. Those injury mitigations that lead to fact that the accident is not reported to the data-base anymore are interpreted as accident avoidances for this paper.

It is rather clear that from real world accident data one typically cannot decide for a given accident of category A to what extend the severity would be reduced by the safety function of interest. This implies that an accident of category Ax may be mitigated with some probability to Ay for any y < x. It seems unrealistic to assume that we can obtain reliable information on these probabilities.

The described mitigating effectiveness of a safety function leads to the following situation. For all accidents with a certain severity that belong to group Ay we have on one hand a reduction of the number of cases because of injury mitigation (due to the safety function) to accident categories with lower severity. On the other hand we have, again due to the injury mitigating effectiveness of the safety function, that accidents from category Axwith x > y are mitigated to category Ay. This leads to an increase of the number of accidents within category Ay. The reduction on one hand and the increase on the other hand are only observable as a superposition and this makes the quantification of the injury mitigating effectiveness of a safety function rather delicate. Just for the most severe accidents which belong to category An we observe a possible reduction of the number of cases, only. This is because we assume that the safety function of interest does never increase the severity of an accident. So when looking at the effectiveness within a certain group Ax one always has to keep this in mind. Ignoring these facts may lead to completely misleading results.

Let us discuss the following two ways to handle this dilemma of quantification of injury mitigating effectiveness.

One idea could be not to calculate the effectiveness within each group Ax but instead within the aggregated groups Ax^+ which are defined as $Ax^+ := Ax \cup ... \cup An$. I.e. Ax^+ contains all accidents of type A and with accident severity larger or equal to x. Then every injury mitigation from a group Ax to a group Ay will be observed within each effectiveness of the groups Ax^+ to

 $A(y+1)^+$. The idea would be to look at the distribution of the observed crude effectiveness over the different groups Ax^+ for x=1,...n. The effectiveness within such an Ax^+ can be computed from equation (8) with A replaced by Ax^+ . For every calculation of an effectiveness for a subgroup of A such as Ax or Ax^+ also the type of neutral accident has to be classified accordingly and is denoted by Nx or Nx^+ .

Using this approach we are able to circumvent the dilemma of quantification of injury mitigating effectiveness by only considering the groups Ax^+ for some x. Recall that it then is not possible to have downshifts to this group from more severe accidents by injury mitigating. Even though following this proposal we are not able to calculate the effectiveness within a group Ax instead of Ax^+ .

The other approach to be described quantifies lower and upper bounds for the effectiveness within the group of interest, taking into account possible shiftings from groups of more severe accidents to the accident group of interest. Let us assume that we are interested in comparing the effectiveness of two safety functions SC I and SC II on accidents of type A with a specific severity Ax.

In doing so at first completely ignore possible injury mitigation from more severe accident categories and compute the effectiveness within the group Ax just using the observed number of cases. We have argued above that one has to subtract from the observed number of accidents within category Ax the number of mitigated accidents from more severe accidents to that category in order to obtain the pure effectiveness of the safety configuration on accidents of severity Ax. Ignoring this subtraction would lead to an underestimation of the effectiveness of the safety configuration on Ax and therefore yields a lower bound $eff_{min}(Ax)$ of the effectiveness on Ax. In a second step we will obtain an upper bound $eff_{max}(Ax)$ for this effectiveness. The exact procedure will be described below. Having done this we end up with an interval $[eff_{min}(Ax), eff_{max}(Ax)]$ which contains the true but unknown effectiveness of the safety configuration on Ax.

The main idea is to estimate how many accidents at most may have been downshifted from more severe accidents to the category Ax, then to subtract this number from the observed number of cases within category Ax and finally calculate on this basis the upper bound $eff_{max}(Ax)$. For the estimation of the number of accidents which at most may have been downshifted, we first need the following abbreviations (Equations 12):

$$z := x+1$$
 $e_z := eff(Az^+)$
 $eqr_{Az^+} := \frac{\text{No. of vehicles with SC I in } Az^+}{\text{No. of vehicles with SC II in } Az^+}$
 $|Az^+| := \text{No. of vehicles with } Az^+$
 $|Az_1^+| := \text{No. of vehicles with SC I in } Az^+$
 $|Az_1^+| := \text{No. of vehicles with SC I in } Az$

Then the corrected amount of vehicles equipped with SC I in Ax which is needed to calculate the upper bound of the effectiveness reads as follows. (Equation 13)

$$|Ax_{I,corr}| := |Ax_{I}| - |Az^{+}| \cdot \frac{eqr_{Az^{+}}}{1 + eqr_{Az^{+}}} \cdot \frac{e_{z}}{1 - e_{z}}$$
which is equivalent to
$$|Ax_{I,corr}| := |Ax_{I}| - |Az_{I}^{+}| \cdot \frac{e_{z}}{1 - e_{z}}$$
(13)

If now calculating $eff_{max}(Ax)$ using the value $|Ax_{I,corr}|$ instead of $|Ax_{I}|$ then one assumes that all accidents that have been avoided due to SC I out of $A(x+1)^{+}$ have been downshifted to group Ax.

It is worth mentioning that the interval $[eff_{min}(Ax), eff_{max}(Ax)]$, which contains the wanted effectiveness of the safety function is by no means a statistical confidence interval which contains the wanted value only up to some probability.

DATA EXAMPLE (3)

To explain the described procedure let us assume we want to evaluate a secondary safety function SF3 within our fictive data-base. We suppose SF3 to be only relevant to frontal impacts. There have been 4940 vehicles identified, where the equipment with SF3 is known. For an evaluation of the effectiveness of this safety function, a class of neutral accidental situation is needed. We chose those vehicles that were hit from behind since our safety function of interest addresses frontal impacts only.

We again want to evaluate the overall effectiveness, so the accident type of interest A is interpreted as any accident within the database.

As the safety function of interest is a secondary one, we need to evaluate the injury mitigation effectiveness and the injury avoiding effectiveness. According to the section above a more detailed classification of *A* has to be created.

The existing data (that is accident type A) is divided in only two subgroups. A2 contains every vehicle, where at least one occupant is fatally or

severely injured, A1 contains the remaining accident-involved vehicles.

Table 6. Cross-tabulars for calculating odds-ratios

all vehicles within data-		type of accident		
base		N	A	
SF3	no	178	1384	
313	yes	449	3383	
sum		627	4767	

vehicles without any		type of accident	
severely injured occupant		N1	A1
SF3	no	162	1097
yes yes		408	2796
sum		570	3893

vehicles with at least one		type of accident	
severely injured occupant		<i>N</i> 2	A2
SF3	no	16	287
313	yes	41	587
sum		57	874

With this data the effectiveness of each group may be calculated similar to equation (5) as it is shown in (Equation 14):

$$eff(Ax) = 1 - \frac{\frac{\text{No. of cars with SF1 within } Ax}{\text{No. of cars with out SF1 within } Ax}}{\frac{\text{No. of cars with SF1 within } Nx}{\text{No. of cars without SF1 within } Nx}}, (14)$$

for x equal to 1 or 2.

So we obtain the effectiveness within each group as follows (Equation 15).

$$eff(A) = 1 - \frac{3383}{1384} / \frac{449}{178} \approx 3.10\%$$

$$eff_{min}(A1) = 1 - \frac{2796}{1097} / \frac{408}{162} \approx -1.20\%$$

$$eff(A2) = 1 - \frac{587}{287} / \frac{41}{16} \approx 20.18\%$$
(15)

As it is explained in the previous section we so far only obtain a lower bound of the effectiveness within group AI.

For calculating the upper bound of the effectiveness within group AI we need to apply formula (14) and we get (Equation 16)

$$|A1_{1,new}| = |A1_1| - |A2_1^+| \cdot \frac{eff(A2^+)}{1 - eff(A2^+)}$$

$$= 2796 - 587 \cdot \frac{20.18\%}{1 - 20.18\%}$$

$$\approx 2647.6,$$
(16)

which leads to the upper bound of the effectiveness within group *A1* of (Equation 17)

$$eff_{\text{max}}(A1) = 1 - \frac{2647.6}{1097} / \frac{408}{162} \approx 4.17\%$$
. (17)

We end up with (Equations 18)

$$eff(A) \approx 3.10\%$$

 $eff(A1) \in [-1.20\% ; 4.17\%]$ (18)
 $eff(A2) \approx 20.18\%$

How can these results be interpreted?

At the first glance a non-zero overall effectiveness seems strange as we are investigating a secondary safety functions which is supposed not to have an accident avoiding effectiveness. On the other hand it is likely that some cases where injuries were avoided entirely due to the safety function have not been reported in the data base. This is equivalent to an accident avoiding effectiveness.

The effectiveness within the group of vehicles with slightly or not injured occupants (AI) lies within the interval [-1.20% ; 4.17%] (cf. equation (19)). We therefore can not exclude a zero-effectiveness within this group. This would mean a similar behaviour of SC I compared to SC II on vehicles involved in accidents with slightly or not injured occupants.

The effectiveness of SC I compared to SC II within the group of accident-involved vehicles with at least severely injured occupants is rather high. Just recall that the calculated effectiveness is the effectiveness within the entire group A2 and not only within a subpopulation of "sensitive" cases.

To put it all into a nutshell we can state that the main difference of these two safety equipments seems to be an injury mitigating effectiveness that is by far most effective for avoiding severe accidents. So obviously odds-ratios may be used to estimate the injury mitigating effectiveness of a safety equipment.

A last word of caution: It is advisable to compare the different equipment-rates within the various types of neutral accidental situations. It may occur that the calculated effectiveness within some groups of accidental situations results from an increased equipment-rate within the neutral subgroup of accidents instead of a reduction of the equipment-rate within the entire group only. In this case the selection of neutral accidental situations needs to be crosschecked or at least explained.

In our example the equipment-rates within the group of neutral accidental situations differ only slightly (Equation 19)

$$eqr_N = 449/178 \approx 2.522$$

 $eqr_{N1} = 408/162 \approx 2.519$ (19)
 $eqr_{N2} = 41/16 \approx 2.563$,

which seems to be quite reasonable.

If we just do a small modification of Table 6 in order to obtain the following Table 7,

Table 7. Cross-tabulars for calculating odds-ratios

vehicles with at least one		Type of accident	
severely inju	ired occupant	N2	A2
SF3	no	20	287
	yes	41	587
St	ım	57	874

we end up with a more or less vanishing effectiveness of $eff(A2) \approx 0.23\%$. But this is only due to the change of the equipment-rate within the group N2, which is $eqr_{N2} \approx 2.050$ and significantly less than the rates eqr_N and eqr_{N1} .

The other way around is possible as well: A not reliable classification of the group of neutral accidents may also lead to an observed effectiveness even though only the equipment-rates within the group of neutral accidents differ (so-called pseudo effectiveness). As an example, consider Table 8 which again is obtained by applying only slight modifications compared to Table 6.

Table 8. Cross-tabulars for calculating odds-ratios

Cross the district thirthing of the recipient			
all vehicles within data-		type of accident	
b	ase	N	A
SF3	no	178	1384
31.3	yes	459	3527
SI	um	637	4911

vehicles without any		type of accident	
severely injured occupant		N1	AI
SF3	no	162	1097
	yes	408	2796
sum		570	3893

vehicles with at least one		type of accident	
severely injured occupant		N2	A2
SF3	no	16	287
	yes	51	731
sum		67	1018

In this case we end up with the effectiveness within each group as it is shown in (Equation 20)

$$eff(A) \approx 1.17\%$$

 $eff(A1) \in [-1.20\% ; 5.45\%]$ (20)
 $eff(A2) \approx 20.09\%$

So the results seem to be comparable to the results obtained from the original example shown in Table (6). But a closer look on the equipment-rates within the group of neutral accidental situations shows clearly a problem concerning the classification of this group (Equation 21):

$$eqr_N = 459/178 \approx 2.579$$

 $eqr_{N1} = 408/162 \approx 2.519$ (21)
 $eqr_{N2} = 51/16 \approx 3.188$

So the observed effectiveness may be due to the high equipment-rate within the group of neutral accidents. When looking at the equipment-rates within the groups A, AI and A2 we get (Equation 22)

$$eqr_A = 3527/1384 \approx 2.548$$

 $eqr_{A1} = 2796/1097 \approx 2.549$ (22)
 $eqr_{A2} = 731/287 \approx 2.547$

Summarizing, it seems to be clear that the observed effectiveness of 20% within the group A2 is due to the high equipment-rate within the group N2 and nothing else. As a result we may state that if and only if this high equipment-rate is reliable the observed effectiveness is reliable as well.

LOGISTIC REGRESSION AND THE QUANTIFICATION OF THE INFLUENCE OF ADDITIONAL EXTERNAL FACTORS

In drawing conclusions from a statistical analysis one always has to be careful. A causal relationship between two variables always leads to some kind of statistical dependence between these two quantities. The opposite assertion, namely that an existing statistical dependence between two quantities leads to a causal relationship between the corresponding variables, not necessarily is true. The easiest example one may think of is as follows. Assume that one variable Z has a causal relationship to the variables X and Y which are of interest to the investigator. If one consider or observe the variables X and Y only, then there typically will show up some kind of dependence between them. But the true story is that both variables depend on the third one Z. In the context of this paper this could mean that if the driver populations of vehicles equipped and not-equipped with a specific safety equipment are completely different or even disjoint then the observed effectiveness of this safety equipment completely may be due to the difference in the driver population. One easily can think of other examples which in some and even in relevant cases may lead to a significant misinterpretation of the results. In pure statistical theory one therefore usually assumes that the test conditions of the two experiments are completely equal except for the variable of interest. In our context this means that we e.g. assume that all loss of control accidents are almost similar except the equipment with an electronic stability program. Having such an ideal situation at hand, all observed differences in accident outcome between equipped and non-equipped vehicles is due to the electronic stability program for sure. But the above mentioned theoretical assumption is far from being realistic when investigating real world accident data. In reality the equipment of vehicles not only differs up to a single safety function and the driver population rarely is the same for different vehicles. Therefore methodology is needed to deal with this situation.

One simple idea is to create different categories of accidents in which all relevant external variables like driver's age and gender, size of the vehicle, weather conditions at the accident spot, accidental situation etc are as similar as possible. Within every group of such categorized accidents one may compute an odds-ratio as described above for example. The variation of the odds-ratio over the different categories easily may be interpreted as a quantification of the influence of the accident characteristics within a single category. This approach perfectly works if one has sufficient accident data at hand and not too many external variables in mind. If only one of these two hypotheses is not true one ends up with very few cases in each category which leads to non reliable statistical quantities within each category. Even if we only have five external variables in mind for which each of them may take five different values we at least need hundred thousand and more accidents in order to obtain reliable and interpretable results. Thus, even for a rather low number of external variables we are confronted with the so-called curse of dimensionality.

Another possibility in order to quantify the influence of external variables to the accident outcome is given by the statistical concept of logistic regression. A detailed explanation of the concept of logistic regression models may be found in any textbook of categorical data (cf. for example Agresti (1996)). A condensed explanation of the logistic regression approach in the context of accident research can be found for example in Kreiss et al. (2006). Before we start explaining a

brief word of caution is in order. Logistic regression is not able to circumvent the above mentioned curse of dimensionality. The truth is that logistic regression is a statistical tool which is able to deal with a moderate and sometimes even high number of external variables by the price of assuming that the influence of the external variables is to some extend easily structured. From a principle point of view logistic regression assumes that the influence of the external variables to a slightly transformed output quantity is just as simple as a linear influence.

Let us describe the essentials of logistic modelling and assume that we have external variables $x_1, x_2, ..., x_d$ which could take values 0 or 1, in case of gender as an example, or could take numbers (like the age of the driver of the vehicle) and so on. One or more of the variables denotes the coding whether a specific safety function in the vehicle is on or off. Then logistic modelling for the probability $P(A \mid x_1, x_2, ..., x_d)$ of having an accident of type A given that the external variables take the specific values $x_1, x_2, ..., x_d$ reads as follows (Equation 23)

$$P(A|x_1,...,x_d) = \frac{\exp(\beta_0 + \beta_1 x_1 + ... + \beta_d x_d)}{1 + \exp(\beta_0 + \beta_1 x_1 + ... + \beta_d x_d)}.$$
 (23)

For the so-called odds this means (Equation 24)

logit
$$P(A|x_1,...,x_d) = \ln \frac{P(A|x_1,...,x_d)}{1 - P(A|x_1,...,x_d)}$$

= $\beta_0 + \beta_1 x_1 + ... + \beta_d x_d$, (24)

which just indicates the above mentioned linearity assumption of logistic modelling. Routine statistical theory immediately leads us to estimates of the parameters $\beta_1, \beta_2, ..., \beta_d$. The value β_k or equivalently $\exp(\beta_{\iota})$, which is nothing else but an odds-ratio, represents the influence of the external variable number k having all other variables $x_i, i \neq k$, under control, i.e. having them similar for all accidents. It should be stressed again that a specific linear model for the influence of the external variables on the odds is assumed. In various situations this in fact may occur as a strong restriction. For example the logistic approach is not able to describe the behaviour of an external variable for which we have for low and high values a strong influence to the accident outcome and only a moderate influence for moderately large values of the external variable. One external variable for which this in fact is true is belt usage and height of the driver. The safety belt is designed for medium sized people and we indeed observe that rather small and rather tall drivers are less well protected by the safety belt than medium sized drivers.

Moreover it should be mentioned again that we really need a class of accidents neutral to the specific external variable we have in mind in order to be able to compute the above mentioned oddsratio, namely the quantity $\exp(\beta_{k})$, since we only observe specific realizations of the external variables only given that an accident what type ever has happened. In case that A stands for an arbitrary accident then the mentioned odds-ratio just quantifies the influence of the specific external variable to the overall accident outcome (overall influence of the specific variable). In case that A stands for a specific type of accidents (e.g. loss of control accidents or rear-end accidents) then the above described odds-ratio measures the influence of the specific external variable to accidents of the prescribed type only. Of course such an accident type specific influence can be extrapolated to an overall influence just by renormalizing, i.e. multiplying, the accident specific influence coefficient, i.e. the odds-ratio, by the percentage of accidents of type A. To be specific:

If the overall effectiveness of a safety equipment SF1 compared to safety equipment SF2 is wanted, specify a neutral type of accident N first. Define A as "not N" and then apply a logistic regression to gain the effectiveness of the safety function within A. It has to be kept in mind that cases that do not have either SF1 or SF2 equipment are not to be involved in the calculation for the logistic regression. The overall effectiveness then is (Equation 25)

$$OR = OR(A) \cdot \frac{\text{No. of cases within } A}{\text{No. of cases within } A \text{ or } N}$$
 (25)

If instead of the odds-ratio one minus the odds-ratio (this is called the effectiveness of the specific external variable) is considered all stated arguments remain valid.

CONCLUSIONS

This paper shows, that the well researched and statistically sound method of odds-ratios is not only able to evaluate the accident avoiding effectiveness of a single safety function but as well may be used to evaluate the interactions of multiple safety functions as well. It even enables us to evaluate the injury avoiding and injury mitigating effectiveness with some limitations.

The crucial point within this kind of evaluation is the classification of a group of neutral types of accidental situations. The whole algorithm stands and falls with the reliability of this group!

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IN-VEHICLE INTELLIGENT SPEED ADVISORY SYSTEMS

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ABSTRACT

We review research findings on intelligent speed adaptation (ISA) and evaluate a self-contained, on-board speed advisory system that alerts drivers when the prevailing speed limit is exceeded (passive ISA).

Recent developments in technology, including improvements to GPS and other navigation aids, mean that ISA has become a commercial reality rather than an experimental novelty. Passive and active ISA systems are now on sale in Australia.

Extensive trials of ISA throughout the world have demonstrated the potential for significant accident savings as well as other community benefits. There is a compelling case for governments to actively support ISA implementation.

INTRODUCTION

Excessive or inappropriate speed is a significant factor in serious road accidents. Road safety authorities around the world devote considerable resources to addressing the speeding problem particularly compliance with speed limits. One countermeasure that is gaining increasing attention is the use in-vehicle technology to assist drivers keep to speed limits or even prevent the vehicle from exceeding speed limits on all roads at all times. This is known as Intelligent Speed Adaptation (ISA).

Recent developments have meant that the reliability, accuracy and effectiveness of in-vehicle technologies has gone beyond the experimental stage and they are becoming commercially available.

Numerous trials of ISA for more than a decade have demonstrated that it is effective in reducing the risk and severity of accidents and has other societal benefits such as reduced emissions and fewer major traffic disruptions resulting from road accidents. This paper examines the role of speeding in road accidents, the reasons for speeding, ISA technology, trials and limitations of ISA, potential benefits and implementation issues.

CONTRIBUTION OF SPEEDING TO ACCIDENTS

Speed Related Crashes

The New South Wales Roads and Traffic Authority (RTA) defines a "speeding-related accident" as one where:

- The driver was charged with a speeding offence (normally exceeding the speed limit) or
- The Police report stated that the vehicle was speeding or
- The vehicle movement indicated inappropriate speed (not necessarily in excess of the speed limit). For example loss of control or skidding while negotiating a curve when there were no other factors to explain the incident.

Using this definition, the RTA estimates that about 40% of fatal road accidents in New South Wales are speed-related.

It can be seen that there are two aspects to speeding:

- "Excessive speed" where at least one vehicle was exceeding the speed limit and
- "Inappropriate speed" where a vehicle was obeying the speed limit but was travelling too fast for the road conditions.

Reports of road accident statistics do not always distinguish between these categories of speeding but it is expected that most reported cases involve excessive speed. Subject to this caution, Table 1 sets out speed-related crash statistics from several countries.

Table 1

Speed-related crashes

speca related crushes		
Region/Country	% of crashes where	
	speeding was a factor	
New South Wales,	38% of fatals	
Australia (RTA 2005)	17% of all crashes	
United Kingdom	29% of fatals	
(THINK)	12% of all casualties	
USA (NHTSA)	33% of fatals	
New Zealand (ACC)	42% of fatals	
Europe (ECMT)	33% of fatals in some	
	countries	

Speed and injury risk

Common misunderstandings amongst motorists (and perhaps some road safety organisations) are:

- that exceeding the speed limit by a "minor" amount is not a safety problem
- that most road fatalities occur at high speeds and involve vehicles travelling at grossly excessive speeds.

Although it is the case that a high speed crash is much more likely to result in a fatality, there are many more crashes which occur at relatively low speeds and, as a consequence, the majority of fatalities occur at these low speeds.

In the USA a sample of fatal crashes is investigated in detail and in most cases a delta V (the effective speed of impact) is estimated. Between 1993 and 1997 more that half of the deaths to seat-belt wearing drivers involved in frontal crashes occurred at a delta-V of 50km/h or less (NHTSA personal communication).

US Fatalities to seat-belt-wearing drivers in frontal crashes (1993-97)

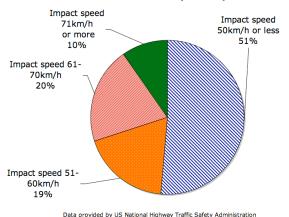


Figure 1. Delta V distribution from US fatalities

Despite improvements to crashworthiness, the proportions for recent vehicles are likely to be similar - the median speed may have increased a few km/h. A 1997 video "Physics of Car Crashes" by the NSW RTA dramatically illustrates the energy involved in a 50km/h collision (Figure 2) and this type of message should be included in road safety campaigns .



Figure 2. Frame from a video illustrating the energy in a 50km/h crash.

Side impacts offer less opportunity for protection of occupants and the median delta-V for fatal injuries is likely to be less than 50km/h. For example, the Australasian New Car Assessment Program (ANCAP) conducted a series of 29km/h side impact pole tests for SUVs with and without head-protecting side airbags (Coxon 2005). HICs of between 5900 and 9000 were recorded for all vehicles without airbags - indicating a very high risk of fatal head injury in this highly intrusive type of crash. Vehicles with airbags generally had HICs associated a low risk of head injury. However, the degree of intrusion (Figure 3) and the injury measurements for other body regions indicate that serious injury would likely occur at slightly higher impact speeds.



Figure 3. Pole impact test at 29km/h (ANCAP)

<u>Crash risk</u> - An analysis of travel speeds and involvement in casualty crashes was undertaken in metropolitan Adelaide in 1997. The data were recently reanalysed (Kloeden 2002). This confirmed an earlier finding that risk approximately doubled for each 5km/h above the prevailing speed limit of 60km/h.

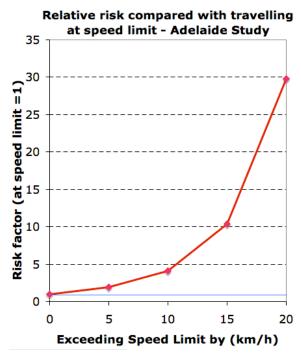


Figure 4. Risk of casualty crash doubles with each 5km/h above the speed limit

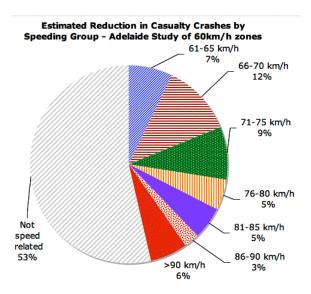


Figure 5. Contribution of speeding groups to casualty crashes.

The same Adelaide study analysed the contribution of each speeding group to the overall speeding problem. As with the case of the US impact speeds, it was found that a large proportion of casualty crashes involved "minor" speeding. It was estimated that 19% of all crashes would have be eliminated if vehicles travelling at between 1 and 10km/h over the speed limit had obeyed the speed limit (Figure 5). This represents 42% of all speeding related crashes and shows that "minor" speeding should be addressed in road safety strategies.

<u>Changing average travel speeds</u> - The Adelaide study estimated the overall crash savings through measures which reduce traffic speeds. It was found that 100% compliance with speed limits would eliminate 21% of all metropolitan casualty crashes and that reducing mean travel speeds by just 2km/h would eliminate 11% of these crashes.

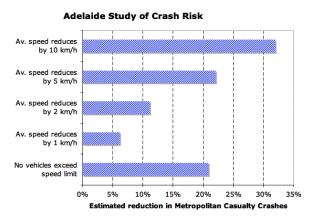


Figure 6. Effect of reducing mean traffic speeds

These findings are similar Nilsson (1993), who found that a 3% reduction in mean traffic speeds produces a 12% reduction in fatal accidents, a European study which found that 15% of injury accidents would be saved if mean traffic speeds reduced by 5km/h (ETSC 2005) and US studies of the effects of speed limit changes (IIHS 2002).

Woolley (2005) describes the results of an analysis of the effects of reducing speed limits of most residential streets in Australia from 60km/h to 50km/h. In New South Wales reportable crashes on residential streets dropped by 25%, with pedestrians and cyclists benefiting most. In Queensland a limited analysis revealed an 18% drop in fatalities. Victoria reported a 59% drop in fatalities and a 12% drop in injury crashes. South Australia found a 20% drop in casualty crashes.

It can be shown that the steep increase in serious crash risk for travel speeds above the speed limit (or the optimum safe speed, in the case of the Australian experience) is due to a "double whammy" effect. On average the impact speed will be higher and, at this higher speed, the probability of serious injury is greater (Paine 1998, Kloeden 2002, OECD 2006). This matches the real-world outcomes illustrated in Figure 4.

WHY DO DRIVERS SPEED?

Some of the common reasons that drivers give for intentionally exceeding the speed limit are that they are in a hurry, that they need to speed up to overtake, that they get a thrill from speeding (Harsha & Hedlund 2007) or that their vehicle/driving ability is better than most other drivers. Some claim that they will slow the traffic or inconvenience other drivers if they drive at the limit. Others report being intimidated into speeding by following drivers such as tailgators.

In a Victorian study associated with the TAC Safe Car (fitted with a prototype speed alert system) 87% of drivers reported that excessive speeding had been inadvertent. (Regan et al 2005). This may be an overestimate for the general motoring population but it does suggest that in-vehicle measures to assist drivers obey speed limits could be quite effective.

Hatfield and Job (2006) report on the attitudes of New South Wales motorists to speeding. A factor is that motorists under-estimate the negative consequences of speeding. For example, participants were asked at how many km/h above the speed limit would the crash risk double (the correct answer is 5 to 10km/h). The average response was 25km/h for urban roads and 30km/h for rural roads. Also of concern, 42% of respondents felt that modern cars made speeding safer. 55% of participants supported some form of speed governing device on cars but 24% opposed this countermeasure..

Mitchell-Taverner & others (2003) found that 14% of surveyed New South Wales motorists normally exceeded the speed limit by at least 5km/h. However, there was a substantial difference across age groups, with 23% of those below the age of 25, 18% of 25-30 year olds,13% of 40-59 year olds and 3% of over 60s.

In order to assess the effectiveness of various types of speed control devices it is useful to identify the different groups of speeding motorists. Paine (1996) made an estimate based on limited data:

Table 2.
Estimated proportion of speeding drivers and contribution to speed-related crashes

contribution to specu-related	er tronies
Category of speeding driver	Est. %
Recidivist - Grossly excessive speeds. Risk taker. May be alcohol affected	3% drivers 10% crashes
Intentional - Feels "safe" at 10- 15km/h over the speed limit. Thinks that risk of booking is low	30% drivers 35% crashes
Inadvertent - Drives a powerful/smooth car which is too easy to drive at over the speed limit or misses speed sign or forgets current speed zoning	35% drivers 30% crashes
Reluctant - Under pressure, drives at the speed of the traffic stream, which is exceeding speed limit. Does not want to impede traffic. Intimidated by tailgators.	30% drivers 25% crashes

Based on this estimate, about two thirds of drivers ("inadvertent" and "reluctant") would be assisted by an advisory system that informed them when they exceeded the speed limit. "Reluctant" speeders would be further assisted if following drivers knew that an ISA system was in operation. The Leeds trial had a sign for this purpose (Figure 7).



Figure 7. Sticker for Leeds trial

About one third of motorists would need a stronger countermeasure, such as a system that prevented the vehicle from exceeding the speed limit. Although somewhat speculative, these ratios are broadly in agreement with support for speed governors reported by Hatfield and Job.

INTELLIGENT SPEED ADAPTATION

In essence ISA systems constantly monitor the local speed limit and the vehicle speed and take action when the vehicle is found to be exceeding the speed limit. This action can be advisory or "passive", where the driver is warned, or "active" where there is some degree of automated control of vehicle speed. To achieve this ISA systems need to know when the vehicle has entered a new speed zone and when variable speed zones are in force (e.g. school zones). Additional ISA features might be the ability to detect

temporary speed zones (such as at accident scenes or near roadworks) and knowledge of advisory speeds such as sharp curves and stop signs (in effect, a stop sign signifies a speed limit of zero).

Types of ISA

Passive systems allow the driver to make a choice on what action should be taken. These can range from a simple audio or visual warning (a flashing light or a beep) to a more sophisticated human-machine interface Some ISA trials have used haptic feedback, where the accelerator pedal became stiffer or vibrated when the vehicle exceeded the speed limit. An alternative is to turn off convenience items such as the radio or air-conditioner when speed limits are exceeded for prolonged periods (Paine 1996).

Active systems reduce (or limit) the vehicle's speed automatically, without intervention from the driver. Methods used to achieve this include throttle control, brake application, engine management system manipulation, fuel limiting or a combination of these. Headley (2005) notes that Adaptive Cruise Control (ACC) can be programmed to "maintain the vehicle speed to that posted" and discusses sign recognition as a way of determining speed limits.

Most of the active ISA systems that have been trialled have an override system so that the driver can disable the ISA if necessary. The provision of such disabling features need not be a concern provided that the times when the system is disabled are logged for monitoring purposes.

One "non-intelligent" form of ISA is top-speed-limiting, where the vehicle is rendered incapable of travelling for prolonged periods in excess of a set top speed. This is simple to achieve with most modern engine management systems - indeed most already have a top speed setting set to unrealistically high values such as 250km/h. Top-speed-limiting based on regional speed limits (e.g. 110km/h plus, say 10km/h in Australia) would be simple to introduce and would be an effective deterrent to vehicle theft and joy-riding.

In Australia top speed limiters set at 100km/h are required on all heavy vehicle built since 1991. However it is evident that there is widespread tampering with these systems (Paine - unpublished report for NSW RTA 2000).

Speed and Location Technology

To function, the ISA system needs to know the location of the vehicle, accurate to a few metres. This location information must be linked to a detailed

digital map (or its equivalent) containing information such as local speed limits, and the location of known variable speed zones (e.g. schools). Advanced ISA has the capacity for real time updating to include information on areas where speed limits should be reduced due to weather conditions (rain, snow, ice, fog) or around accident scenes and roadworks.

There are three main types of technology currently available for determining location (and, in turn local speed limits). Some of these also determine the speed of the vehicle independent of the vehicle's own speedometer (which can be out by as much as 10%). These technologies are:

- GPS
- Radio Beacons
- Dead Reckoning

Global Positioning System (GPS) - GPS is based on a network of satellites that constantly transmit radio signals. GPS radio receivers pick up these transmissions and, by comparing the signals from several satellites, are able to pinpoint the receiver's location, usually to within a few meters (for advanced receivers).

There are currently 24 satellites making up the GPS network and their orbits are configured so that a minimum of five satellites are generally available at any one time for terrestrial users. In theory four satellites is the minimum number of satellites required to determine a precise three dimensional position (latitude, longitude and altitude).

Despite its popularity, GPS is subject to a number of fundamental problems related to the accuracy of the determined position. The receiver still gets the signal from the satellites, but due to satellites ephemeris uncertainties, propagation errors, timing errors, multiple signal propagation paths (eg reflected signals) and receiver noise, the position given is not always accurate (Kao 1991). Usually these inaccuracies are insignificant for car navigation purposes but sometimes they can be up to hundreds of metres. Furthermore, because GPS relies upon a signal transmitted from a satellite in orbit it does not function when the receiver is underground or in a tunnel and the signal can become weak if tall buildings, trees or heavy clouds come between the receiver and the satellites.

Current improvements being made to the GPS satellite network and receivers will help to increase GPS reliability and accuracy but are unlikely to overcome some of the fundamental shortcomings of GPS.

Radio beacons - Roadside radio beacons work by transmitting data to a receiver in the car. The beacons constantly transmit data, which the car mounted receiver picks up as it passes each beacon. This data could include local speed limits, school zones, variable speed limits or traffic warnings (roadworks, weather, etc).

Beacons could be placed near (or on) speed limit signs or other roadside furniture or in the road itself. Mobile beacons could be deployed (that would override fixed beacons or GPS) for use around accident scenes, during poor weather or during special events.

A problem with beacon technology is that the vehicle needs to be in the proximity of a beacon in order to determine the speed limit. There would need to be some redundancy in the system to allow for broken beacons and transmission errors. Also, to work properly, every intersection where the roads had different speed limits would need a set of beacons (eg side roads joining arterial roads).

Dead reckoning - Dead reckoning (DR) uses a mechanical system linked to the vehicle's driving assembly, to predict the path taken by the vehicle. By measuring items such as the rotation of the road wheels and the angle of the steering wheel a reasonably accurate estimation of the vehicle's speed and location can be made. More accurate systems rely on specialised sensors (accelerometers, flux gate compass, gyroscope). However, dead reckoning requires the vehicle to begin at a known, fixed point near the start of the journey. Inaccuracies result from a variety of sources, including changes to tyre diameter as the tyres warm up. Errors gradually accumulate and become unworkable unless there is periodic correction with a new reference point. For this reason dead-reckoning needs to work in conjunction with another system, such as GPS. Some top-end GPS based navigation systems use dead reckoning as a backup system in case GPS signal is lost (such as in tunnels).

Map matching - Once the vehicle location has been determined, the accuracy can be checked by digital map matching. Under this scheme, the assumed location is compared with known roads (such as those available from a navigation map) and the system snaps to the most likely location on a known road. A check is also made against the last known position to determine if the new location is physically reasonable.

The most accurate ISA systems possible today use a combination of GPS, dead reckoning and map matching (Basnayake 2004, Calafell 2000, Kao 1991)

Optical recognition systems - So far optical recognition technology has been focussed on recognising speed signs only, however other roadside objects, such as the reflective 'cats eyes' that divide lanes could possibly be used. This system requires the vehicle to pass a speed sign (or similar indicator) for data. As the system recognises a sign the speed limit data is obtained and compared to the vehicle's speed. The system would use the speed limit from the last sign passed until it recognises a speed sign with a different limit.

As with beacons, if speed signs are not present or are obscured the system does not function. This is a particular problem when exiting a side road onto a main road (the vehicle may not pass speed sign for some distance). The accuracy, reliability and effectiveness of optical recognition technology remains unproven in ISA and it appears that the other technologies are more suitable.

EVALUATIONS OF ISA

The table in the Appendix summarises ISA trials conducted in several countries. There have been at least 25 trials conducted in a total of 14 countries, with the notable exception of the USA.

Carsten's review (2004) indicates that, on the whole, these trials have exceeded the organisations expectations. However, Carsten notes that some trials have missed an opportunity for collecting pertinent data.

Accuracy and Reliability of ISA

A warning resulting from an incorrect speed limit would be a nuisance for an advisory system. The same errors in an active system could have serious road safety disadvantages, depending on the level of control of the system and the ability of the driver to over-ride the system. A typical example of a safety hazard would be a car travelling at 110km/h on a motorway where the ISA system unexpectedly reduces the vehicle speed to 50km/h, due to a GPS or mapping error. It is therefore important that sources of possible errors be identified and minimised.

The overall system comprises three major components (Figure 8):

- DRIVER/VEHICLE
- ISA SYSTEM
- SPEED LIMIT DATABASE

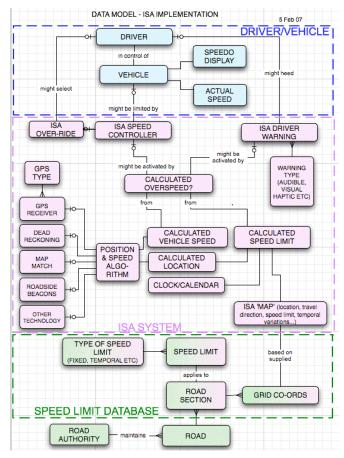


Figure 8. Data model of ISA

The ISA system includes any components that determine the vehicle's position or velocity, and compares it with a map of speed limits to determine whether the vehicle is speeding. For passive systems it also includes the way in which the driver is warned of excess speed (flashing lights, sounds, voice prompts, etc). For active systems it includes the controls that are used to automatically prevent speeding.

The speed limit database contains all information related to any digital map or other information system that is used to determine local speed limits, some of which may be temporal (such as school zones).

The list below shows the potential faults for each of the three main areas of ISA

Driver/vehicle

 The driver may ignore, misunderstand or not notice a speed warning

- The driver may perform an unintended action in reaction to a speed warning (e.g. become distracted)
- For active systems, the driver might over-ride the system, or might not be aware that it is not operative (over-ridden by a previous driver).

ISA System

- The speed warning may be a false alarm (e.g. wrong speed limit or incorrect vehicle speed)
- The speed warning may fail to activate when the vehicle is actually speeding,
- The vehicle speed or position may be inaccurate or inoperative (GPS 'drop out', beacon failure)
- Time or date incorrect (time dependant variable speed zones affected)
- System may be out of operational range (e.g. no beacon close enough or boundaries of digital map reached)
- With active ISA, the speed controlling mechanism fails to activate or sets to the wrong speed
- The override, if any, might not work
- Failsafe operation might not work with an active system (driver loses throttle control)

Speed Limit Database

- Variable speed limits are not included
- Timing information for time dependent variable limits is incorrect (e.g. holidays)
- A speed limit changes but the digital map is not updated
- Road path (alignment) changes but the digital map is not updated
- Wrong speed limit is assigned
- Coordinates of map are incorrect/inaccurate
- Road is not mapped

ISA ON SALE IN AUSTRALIA

SpeedAlert

In mid-2006 a Sydney company, Smart Car Technologies, began commercial sales of a GPS-based speed limit advisory system.

SpeedAlert is a software package that is designed to work with compatible PDAs and programmable mobile phones. SpeedAlert works with GPS to pinpoint the position of the car. Using a pre-recorded database of speed limits, the software is able to recognise the current speed zone the car is travelling in. Using GPS, SpeedAlert is also able to accurately

calculate the speed of the vehicle and so is able to warn the driver, using audible and/or visual alerts, if the car exceeds the speed limit at any time. No connection to the vehicle's speedometer system or other components is required.

The system is designed to be highly portable and can be easily transferred between vehicles. Installation involves an optional cradle to hold the PDA, a power cable to a cigarette lighter socket and a bluetooth GPS receiver placed on the dash. The software is also designed to work with PDAs and mobile phones that have built-in GPS reception. Costs range from US\$90 for software and a 12 month update subscription to about US\$500 for a PDA with built-in GPS receiver and the SpeedAlert software and update service. Updates are downloaded over the Internet and are typically several megabytes.

Speed zone information - SpeedAlert uses a patented layered mapping system. The first layer is a polygon defining the default speed limit for a region. The next layer comprises strips/tracks for all roads that do not have the default speed limit. The top (priority) layer has polygons defining school zones and similar safety-related areas. Once the program has established communication with the GPS receiver it analyses the speed zone database and prominently displays the current speed limit as large black numerals inside a red circle (Figure 9). The current

vehicle speed is displayed in smaller numerals below the speed limit.

If the speed limit is exceeded the numerals turn to red. Depending on user settings (2 or 5km/h over the limit), an audible beep is activated. The beeps continue until the vehicle speed is decreased. There are two levels of beeping one beep per second or two beeps per second depending on the amount



Figure 9. SpeedAlert display

by which the speed limit is exceeded.

The driver can choose to mute the beep, but the mute facility is over-ridden in the vicinity of a school zones or fixed speed cameras.

At the time of the evaluation the system was not able to display variable or temporary speed limit information, such as on some freeways and in the vicinity of roadworks. However it did alert drivers when travelling along a road with variable speed limits.

The database has school zone information. When the vehicle is approaching a school zone the unit announces this by voice and a logo appears in the lower left of the screen. Once the school zone is reached the unit displays the appropriate speed limit information, depending on the time of day and day of week.

Irrespective of the time of day, the voice alert always activates in school zones and always beeps if the current speed limit is exceeded by more than 1km/h. This is in recognition that children might be crossing the road outside the designated school zone hours.

The system also gives a voice alert when approaching railway crossings, fixed speed cameras, red light cameras and bus lane cameras.

On-road trials - The authors have used SpeedAlert for many road trips within the Sydney metropolitan region. Some refinements to the user interface and some updates to the maps were implemented during this period. Key points from the evaluation are set out below.

The user interface was found to be simple to use and intuitive. Once the program loads and is communicating with the GPS unit there is no need for driver intervention - it simply displays the current speed limit and vehicle speed and will beep if the speed limit is exceeded. Importantly, there is no need to look at the screen at all while driving, unless there is uncertainty about the current speed limit. In any case, this likely to be a less distracting task than scanning the roadside for the occasional speed limit sign.

Knowing the speed limit, the driver monitors and adjusts the vehicle speed in the normal way. If the unit starts to beep then it means that either the speed has crept up over the speed limit or the speed zoning has changed. In either case the driver reduces speed until the beeping stops. There is no need to look at or touch the PDA during this sequence. For the evaluation the tolerance for audible warning was set at 2km/h and it was found to be easy to travel at or below the speed limit without an undue number of audible alarms.

For most of the time the system worked well. However occasionally it reverted to the default 50km/h speed limit while travelling on arterial roads. The system apparently decided that the vehicle had left the arterial road and was in a 50km/h zone. This was mostly resolved by fine-tuning the digital map to better define some portions of the arterial roads. Algorithms to better detect and deal with remaining situations (such as spurious GPS positions) are under development.

From a "warm" start the GPS receiver usually takes between 30 seconds to a minute to establish location. This means that the first few hundred metres of a journey are not covered. After this period the system was found to be very reliable and accurate.

One of the authors has travelled approximately 6000km with SpeedAlert in operation and has noted instances when the system appeared to be unreliable. In a typical journey of 50km through suburban Sydney it is estimated that the system would lose the signal or display an inaccurate reading for no more than about 30 seconds. This equates to about 99% accuracy, which is considered acceptable for a passive system. Occasionally, however, the GPS receiver was unable to obtain a reliable signal and several kilometres were travelled with the system out of action. Also, as expected, the system did not operate in tunnels and took several seconds to reacquire the signal on exiting the tunnel.

Most of the evaluation was conducted using an imate PDA-N device with built-in GPS receiver (SiRF starIII).

It is often difficult to obtain good GPS reception in city streets with tall buildings. However, with Sydney city traffic there is little opportunity to drive at anywhere near the posted speed limits most of the time so this is not seen as a serious obstacle to use of the system. Nevertheless, it is important that drivers using this type of advisory system are made aware of its limitations and do not become complacent about monitoring their speed.

<u>Speed limit database</u> - At the time of this evaluation the mapping database covered the Sydney metropolitan area. Mapping is underway for the remainder of Australia.

In order to prepare a complete and accurate database, Smart Car Technologies has developed an efficient but labour-intensive method of mapping the roads of interest. A two-person team drives along roads that might contain non-default speed limits. Speed zone changes, the road geometry and other features are recorded using a GPS-equipped laptop computer. Multiple trips are used to improve accuracy.

It is understood that most of the trials of ISA have involved similar mapping exercises due to the lack of good speed limit information from road authorities.

There is evidently a need for pooling of resources and greater co-operation from road authorities to create and maintain the necessary speed limit databases for widespread implementation of ISA (ETSC 2006).

Speedshield

Melbourne company, Automated Control Systems (ACS), has developed an active speed control system which has been in operation in industrial locations such as warehouses since 2003. The system is in widespread use on forklifts and similar vehicles by a number of major Australian companies.

The company further developed this system for use in cars and commercial vehicles. In 2006 ACS was awarded a contract to conduct ISA demonstration projects with the Transport Accident Commission of Victoria and with the Office of Road Safety and Main Roads WA of Western Australia. A total of 100 units will soon be in operation in these two Australian states. One aim is to generate public demand for ISA. ACS is also currently running an on-road trial with trucks in Victoria.

Speedshield uses a combination of GPS and deadreckoning to establish vehicle location and local speed limits. Radio beacons and wireless communication are used to provide speed zone database updates. The system accommodates temporary speed control e.g. roadworks, accidents

etc. by use of bollards fitted with roadside transceivers and time based limits such as school zones.

Figure 10 shows the display used in the demonstration project. The device provides alerts for current speed zone, speed zone



Figure 10. Speedshield display and controls

changes and over speed. Full vehicle speed control operates when optionally selected.

A control module is installed between the accelerator pedal and the engine and mirrors the driver's throttle movement until the speed limit is reached, at which stage the module will hold or reduce the throttle signal. An optional over-ride is available where the driver briefly pushes the accelerator pedal to the floor.

Other features of particular interest to fleet operators are driver identification (only authorised people can drive the vehicle), crash data logging, vehicle operation reports and despatch management.

The current installed cost of the basic Speedshield system is about US\$2000. With large-scale production this should reduce to a cost that is comparable to in-car navigation systems.

BENEFITS OF ISA

Road accident savings

Carsten (2001, 2004 and 2005) provides a review of various trials and estimates of the effectiveness of ISA. He considers three levels of control: advisory, voluntary (active but driver can disable) and mandatory (active all the time) and three types of speed limit: fixed, variable and dynamic (adjusting to current road conditions). Table 3 sets out "best estimates" of injury and fatal accident reductions.

Table 3. Estimates of ISA savings by crash type

System Type	Speed Limit Type	Injury	Fatal
Advisory	Fixed	10%	18%
	Variable	10%	19%
	Dynamic	13%	24%
Voluntary	Fixed	10%	19%
	Variable	11%	20%
	Dynamic	18%	32%
Mandatory	Fixed	20%	37%
	Variable	22%	39%
	Dynamic	36%	59%

For comparison, based on logged data from a trial of a passive ISA system working with fixed speed limits, Regan (2006) estimated that the system could reduce fatal accidents by 8% and serious injury crashes by 6% but noted that these were likely to be under-estimates

From Table 3, estimates of savings for mandatory ISA are about twice that for advisory ISA. This broadly agrees with the proportions provided in Table 2, on the assumption that advisory ISA will generally only be of benefit for inadvertent or reluctant speeders.

Mandatory ISA and, to a lesser extent, voluntary ISA would also cover "intentional" speeders. Although, in theory, "recidivist" drivers would also be covered by mandatory systems, experience with heavy vehicle top-speed limiters in Australia suggests that extra monitoring functions would need to be in place to discourage tampering. This is quite feasible with ISA - many of the ISA trials have collected data for later analysis.

Environmental benefits

Most ISA trials have reported reductions in fuel consumption. Carsten (2005) describes the modelling of ISA on various types of roads. Fuel consumption savings were: 8% for urban roads, 3% for rural roads and 1% for motorways. Results of emissions modelling were mixed and so no environmental benefits were assumed. Regan (2006) reported no significant fuel consumption reductions for an ISA trial in Melbourne. However, it should be noted that widespread adoption of ISA, vehicle manufacturers are more likely optimise drive system performance to suit typical driving conditions, rather than the marketed top speed capability of the vehicle. This should ultimately result in reduced emissions. There are also noise and amenity benefits (OECD 2006)

Travel times and other issues

Regan (2006) reports that ISA did not increase travel times during the extensive trial in Melbourne, Australia. Many other trials have reported little or no increase in travel times.

Based on modelling, Carsten (2000) estimated a maximum overall increase in travel time of 2.5%. However, this does not appear to take account of a reduction in major traffic disruption resulting from crashes avoided by widespread implementation of ISA.

Paine (1996) noted that urban network capacity is generally constrained by locations where the traffic is moving at much lower speeds than the statutory speed limit therefore ISA is unlikely to have adverse effects on road network efficiency. Speeding in urban areas is essentially a form of queue-jumping and there is no net advantage to the community from this practice. ISA trials have supported this conclusion (OECD 2006).

Paine also evaluated the effects of ISA on overtaking practices. It was noted that travelling at excessive speed to complete an overtaking manoeuvre is a highly risky practice (the time saved through overtaking is likely to be offset by an equivalent decrease in life expectancy) but, if it is deemed necessary to allow temporary ISA over-ride in these circumstances, then a time-limit of about 20 seconds would be appropriate. However, in planning an overtaking manoeuvre the driver must take a range of factors into consideration and the potential speed of overtaking is one of these factors. Plowden & Hillman (1984) point out that the main effect of a speed limiter is that "the driver of a high-performance

vehicle would no longer perform certain manoeuvres which he now regards as safe".

GOVERNMENT SUPPORT FOR ISA

A 2006 OECD/ECMT report on speed management supports the introduction of ISA and recommends that governments develop digital speed limit databases.

In a 2006 report, the European Transport Safety Council states:

- ISA technologies do work, are robust and reliable. They are technically simple, much simpler than other automatic devices such as collision avoidance systems
- Delivering and maintaining the relevant map data for ISA is not a problem, provided that legislation is there to ensure action is undertaken in a harmonised way.
- The substantial accident reductions to be gained from ISA outweigh its costs, particularly if ISA fitment was required by law. Doing nothing or achieving speed reduction by other means will turn out more expensive in the end than implementing ISA technology.
- Liability is a "red herring": industry has already implemented other support systems (advanced cruise control, etc.) that intervene in vehicle control to assist the driver without being concerned about liability.
- There is no single vehicle technology remaining to be implemented - neither on the market nor in development - that offers the same safety potential as ISA.
- Speed management is a government task and the European governments will realise important economic benefits for their citizens if they decide to encourage and eventually require them to install ISA in their cars. EU countries should therefore wait no longer for industry to act but set the scene themselves. They should as a first step promote the industry's efforts by supporting additional research and standardisation, by introducing tax cuts as incentives to install ISA and becoming first customers of ISA technology. As a second step, they should require ISA by law.

In 2003 the New South Wales Parliament Staysafe Committee commenced an enquiry "Speed and motor vehicles: Vehicle-based measures to monitor, manage and control speed". A report is due to be released during 2007 (Faulks 2007). Late in 2006 the Committee agreed to the following recommendations relating to ISA:

 that there be a regulatory requirement for top speed limiting of all new vehicles and a review of speedometer scales

- that trials be conducted of ISA in New South Wales, including a special trial for novice drivers.
- that the Roads and Traffic Authority provides and supports digital mapping, speed zone databases and other information associated with ISA.
- that consideration be given to incentives for ISA.

These recommendations reflect the difficulties that ISA faces without active support from government. In particular, there is a need for governments to assist with the hurdle of preparing digital maps of speed limits so that ISA systems can be used throughout the nation

In addition it would be helpful if government organisations (and large corporations) embraced ISA technology by making it a requirement for fleet vehicles. Clear, co-ordinated messages to drivers about the safety consequences of exceeding the speed limit are also needed.

CONCLUSIONS

Recent developments in technology, including improvements to GPS and other navigation aids, mean that ISA has become a commercial reality rather than an experimental novelty. Passive and active ISA systems are now on sale in Australia but are limited by the geographical extent of speed limit mapping.

Extensive trials of ISA throughout the world have demonstrated the potential for significant accident savings as well as other community benefits.

There is a compelling case for governments to actively support ISA implementation through:

- a) assistance with the mapping of speed limits and the maintenance of databases
- b) being the first major customers for commercial ISA systems
- c) inclusion of ISA in fleet vehicle purchasing policies and occupational health and safety guidelines
- d) promoting the benefits and functionality of ISA
- e) introducing financial incentives such as tax concessions
- f) educating motorists that most fatalities occur at surprisingly low impact speeds and that just a few km/h over the speed limit greatly increases the risk of a serious injury crash.
- g) introducing subsidised ISA rental/purchase schemes for novice drivers

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Appendix - Summary of ISA Trials

Country	Region	Year	Participants	Type of ISA
Sweden	Lund	1992	75	Active
Sweden	Almqvist & Towliat	1993	16	Active + Passive
Sweden	Ezlov	1996	92	Passive
	Borlange		400	Passive
Sweden	Umea	1999	4000	Passive
Sweden	Lund	1999	290	Active
	Lidkoping		280	Active (150) + Passive (130)
Netherlands	Tilburg	1999	20	Active
Sweden, Spain & Netherlands	-	1997	20-24 per country	Active
Hungary	Debrecen	2003	20	Active + Passive
Spain	Mataro	2003	19	Active + Passive
UK	Leeds	1997	24	Active
UK	Leeds	2003	80	Active
Denmark	Aalborg	2000	24	Passive
Finland	-	2001	24	Passive
France	Several locations	2001	100	Active + Passive
Belgium	Ghent	2002	20	Active
Belgium	Ghent (DIVOTE)	2002	100	Passive
Austria	RONCALLI project	2004	=	Passive
Norway	Karmoy	2004	50	Passive
Australia	Melbourne	2003	23	Active/Passive
Canada	Ottawa	2005-6	10 + 10	Passive "Otto Mate" + "Imita"
Canada (pending)	Ottawa	2007	50	Passive "Belonitor"
Australia	Sydney	2006	20+	Passive "SpeedAlert"
Australia	Melbourne	2006-7	3 + 50 in 2007	Active/Passive "Speedshield"
Australia	Western Australia	2006-7	3 + 50 in 2007	Active/Passive "Speedshield"

This list is based on published reports. There are likely to be other trials that do not appear in this table.

AN ANALYSIS OF VIOLATIONS ASSOCIATED WITH INTERSECTION-CROSSING-PATH CRASHES

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National Highway Traffic Safety Administration Washington D.C., United States Paper Number 07-0284

ABSTRACT

This paper identifies and analyzes violations associated with intersection-crossing-path crashes for the purpose of providing support for development of effective collision avoidance countermeasure systems including the Cooperative Intersection Collision Avoidance System for Violation (CICAS-V) project. The methodology begins by addressing multi-vehicle crashes at intersection / intersection-related junctions subdivided by their respective traffic control devices. This is followed by translating crashes into subsets of two-vehicle crossing-path crashes and analyzing them in detail for their respective violations at various traffic control devices.

The analysis utilizes 2004 General Estimating System (GES) national crash data-files to arrive at the quantitative estimates. There were 1,035,000 two-vehicle-crossing-path crashes at intersections. A majority of the crashes involved vehicles at Straight crossing-paths followed by vehicles at Left turn across path / Opposite direction and Left turn across path / Lateral direction. The analysis provides adequate evidence of violators, the major contributors being *Failure to Yield*, which is due to the misjudgment of gap, and *Running a red light /Stop Sign*. Nearly half the crashes were at signalized intersections and the remaining at non-signalized intersections. For vehicles at Stop Signs, a majority of them were at a two-way Stop Signs.

The paper uses a novel approach by addressing pairs of vehicles and their interactions with each other at crossing-paths. The paper approaches violations by looking at the number of violating vehicles involved in each multi-vehicle crash situation. Pre-crash movement, critical event, and the type of traffic control device are utilized to identify the violating vehicle in each of these situations.

INTRODUCTION

The purpose of the paper is to determine the scope of violations at crossing-path intersection crashes using

the National Automotive Sampling System (NASS)/ General Estimating System (GES) 2004 database of the National Highway Traffic Safety Administration (NHTSA). The paper addresses key areas of precrash behavior like critical event and vehicle maneuver combined with infrastructure components like traffic control device and junction type to estimate violations that produce crossing-pathintersection crashes.

Through the Cooperative Intersection Collision Avoidance Systems to avoid Violations at Stop Signs and Signals (CICAS-V) initiative, the USDOT is working in partnership with the Original Equipment Manufacturers(OEM) and State and local departments of transportation to pursue an optimized combination of autonomous-vehicle, autonomous-infrastructure and cooperative communication systems that potentially address the full set of intersection crash problems

The paper begins with the classification process and presents a general description of all crashes in the United States for their junction types. This leads to intersection-and intersection-related junctions and introduces multi-vehicle crashes at these junctions. This is followed by restricting the analysis to two-vehicle crashes and separating the data for their traffic control devices and their respective type of crossing-path.

The intermediate part of the paper presents the transformation process and describes the need for the transformation of data to address the crash situation. The paper progresses from crashes to vehicles and expands the available set of traffic control devices into appropriate combinations that address the crash situation. The paper introduces violations at this point and separates the vehicles into pairs of cited violations at intersections and identifies the violating vehicle among each pair.

The latter part of the paper presents a process for consolidation of uncited violations with cited violations so as to provide total estimates for all violations at intersections. The process progresses through a series of steps by combining certain precrash scenarios like pre-event maneuver and critical event to arrive at conclusions about the unaccounted violations.

PREVIOUS WORK

Chovan et al. performed crossing-path crash studies using the Crashworthiness Data System (CDS) to device countermeasure concepts for the Intelligent Transportation System program. One part of the analysis dealt with straight crossing-path at signalized and un-signalized intersections [5, 6]. However, these studies did not distinguish crashes based on traffic control devices. Chovan et al. [7] also performed an analysis on vehicles turning left at intersections while the other vehicle was approaching from the opposite direction. This study did not differentiate between signalized and un-signalized intersections. Ragland and Zabyshny [4] developed taxonomy of Crossing-path crashes for the intersection decision support (IDS) project. The project would provide information to drivers through their Decision Support System builds on and previous work to provide possible IDS countermeasures at intersections with crossing-paths. However, the paper does not discuss the types of violations and their implications at these crossing-paths.

Wang et al. [8] produced a detailed report on the problem size assessment and statistical crash descriptions for intersection crossing-path-crashes using such measures as number of crashes, number and severity of injuries, number of fatalities, crash involvement rate, and crash involvement likelihood. In 2001, Najm et al. [1] performed a detailed analysis of the intersection problem by analyzing it for all types of junction; not just intersections. The paper deals with the understanding of the pre-crash scenario in order to evaluate proposed countermeasures for the intersection problem. The paper separates the intersection crashes by the pre-crash movement based on the type of crossing-path. Najm's paper serves as a model for the current paper. However, the current paper adds to the analysis by accounting for underreported violations through a combination of critical event and pre-crash maneuvers to arrive at reasonable estimates.

ANALYSIS

The analyses of crossing-path intersection/intersection-related crashes are broadly classified into the following three processes:

- Classification process
- Transformation process
- Consolidation process

1. Classification process

The process begins with a general description of the crash scenario and quantifies all crashes at intersection and intersection-related junctions. This is followed by restricting the analysis to two-vehicle crashes and separating the data into their respective crossing-path crashes. The activities involved in these processes are described below.

Type of Junction

The analysis begins by identifying the type of junction involved in crashes. Since 1992, junctions are broadly classified into *interchange* and *non-interchange areas*. The description of this is given below:

Interchange/ Non-interchange-The interchange area [3] is the area around a grade separation which involves at least two traffic ways. Included within its boundaries are: (1) all ramps which connect the roadways, and (2) each roadway entering or leaving the interchange to a point 30 meters beyond the gore or curb return at the outermost ramp connection for the roadway. One may find included within interchange area intersections, driveway accesses, and, of course, roadway sections which non-junctions are. This is illustrated in Figure 1[3].

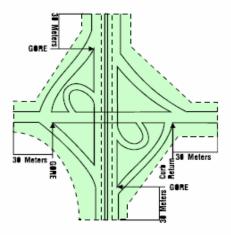


Figure 1. Interchange and Non-interchange areas.

These areas are further classified into junction types as give below:

Non-Interchange

Code 0 Non-Junction

Code 1 Intersection

Code 2 Intersection Related

Code 3 Driveways, Alley Access, Etc

Code 4 Entrance/Exit Ramp

Code 5 Rail Grade Crossing

Code 6 On a Bridge

Code 7 Crossover Related

Code 8 Other, Non-Interchange

Code 9 Unknown, Non-Interchange

Interchange Area

Code 10 Non-Junction

Code 11 Intersection

Code 12 Intersection Related

Code 13 Driveways, Alley Access, Etc.

Code 14 Entrance/Exit Ramp

Code 16 On a Bridge

Code 17 Crossover Related

Code 18 Other Location in Interchange

Code 19 Unknown, Interchange Area

Combining interchange and non-interchange areas for all junctions, it is seen from Table 1 that there were 6,170,000 crashes in the United States in 2004. Among them, non-junctions account 2,768,000(45%) of the crashes forming the biggest contributor followed by intersection and intersectionrelated junctions accounting for 1,304,000(21%) and 1,176,000(19%) of the crashes. Driveways and alleyaccess account for 568,000(9%) while enter/exit ramp account for 184,000(3%) of the crashes. Bridges, rail grade crossing, crossovers and others all together account for 170,000(3%) of the remaining crashes.

Table 1.
Distribution of all crashes for their junction types based on GES 2004

	GES		
Type of Junction	Code	Crashes	Pct %
Non-Junction	0,10	2,768,000	45%
Intersection	1,11	1,304,000	21%
Intersection Related	2,12	1,176,000	19%
Driveway, Alley access	3,13	568,000	9%
Enter/Exit ramp	4,14	184,000	3%
On a bridge	6,16	99,000	2%
Others	8,18	45,000	1%
Crossover Related	7,17	11,000	0%
Rail Grade crossing	5,15	15,000	0%
Grand Total		6,170,000	100%

For the purpose of this study, the analysis is restricted to intersection and intersection-related junctions which are defined as follows: Intersection: An intersection [3] is a type of junction which: (1) contains a crossing or connection of two or more roadways not classified as a driveway access or alley access, and (2) is embraced within the prolongation of the lateral curb lines or, if none, the lateral boundary lines of the roadways. Where the distance along a roadway between two areas meeting these criteria is less than 10 meters, the two areas and the roadway connecting them are considered to be parts of a single intersection.

Intersection-related: Intersection-related [3] means that the first harmful event: (1) occurs on an approach to or exit from an intersection, and (2) results from an activity, behavior or control related to the movement of traffic units through the intersection. Among the many types of intersections, a 4-leg intersection is used to illustrate the areas of concern which is shown Figure 2[3].

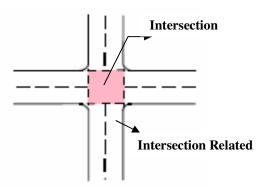


Figure 2. Intersection and intersection-related junctions.

It is seen from Table 2 that intersection and intersection-related crashes account for 2,480,000 of all crashes in the United States. Among them, intersections account for 1,304,000(53%) of the crashes and intersection-related crashes account for 1,176,000(47%) of the crashes. Also, 1,278,000 (52%) of them occur at a non-interchange/intersection and 1,158,000 (46%) of them occur at a non-interchange / intersection-related junction. Also, Interchange / intersection and interchange / intersection-related junctions contribute to only around 1% each. It should be noted that intersection-related crashes were included to account for any intersection crash erroneously coded as intersection-related crashes.

Table 2.
Distribution of intersection / intersection
-related crashes subdivided by the interchange
and non-interchange areas.

Type of Junction	GES Code	Crashes	Pct %
Intersection		1,304,000	53%
Non-Interchange/			
Intersection	1	1,278,000	52%
Interchange/			
Intersection	11	26,000	1%
Intersection Related		1,176,000	47%
Non -Interchange/			
Intersection-Related	2	1,158,000	46%
Interchange/			
Intersection-Related	12	18,000	1%
Grand Total		2,480,000	100%

Table 2 summarizes the distribution of that Intersection/ Intersection-related crashes and leads to the distribution of vehicles involved in crashes.

Two-Vehicle-crashes

The data for intersection and intersection-related crashes from Table 2 are separated into single-and multi-vehicle crashes in Table 3. Multi-vehicle crashes are further separated into two-vehicle and greater-than-two-vehicle crashes. Table 3 also introduces traffic control devices associated with intersection / intersection-related crashes. The analysis utilizes three traffic control devices namely *Colors, Stop Sign* and *No Control*. The GES codes representing the traffic controls are as follows:

Code 00 No Controls Code 01 Signal Code 21 Stop Sign

According to the GES variable code manual, a vehicle is coded to be on *Colors* if the signal processes through the green, amber and red times [2]. A *Stop Sign* is coded in the police accident report if at least one vehicle involved in the accident was present at a Stop Sign. *No Control* is coded for vehicles if at the time of the crash, there is no intend to control (regulate or warn) vehicle traffic. This variable also applies when statutory warnings, deactivated or inactivated signs apply.

It is seen from Table 3 that two vehicle crashes account for 2,061,000(83%) of the intersection/intersection-related crashes followed by single and more-than-two-vehicle crashes accounting for 241,000(10%) and 177,000(7%) of the crashes. For the purpose of the current study, the analysis is

restricted to two-vehicle crashes, since every vehicle is dynamically related to only one other vehicle. Also, this facilitates the process of separation. The single and the greater-than-two vehicle crashes, as seen by the shaded region in Table 3, are excluded in the subsequent analysis.

Among traffic control devices, *Signals* account for 1,214,000(49%) of the crashes followed by *Stop Signs* which account for 569,000(23%) of the crashes. *Uncontrolled intersections* account for 536,000(22%) of the crashes. All other types of controls like, *yield signs*, *warnings signs* etc account for 160,000(6%) of the crashes as seen in Table 3.

Table 3.
Distribution of intersection / intersectionrelated single-, two-vehicle and greater-than-twovehicle crashes against their traffic control
devices.

Traffic control Device	Single vehicle	Two vehicles	Greater than two vehicles	Total
Colors	62,000	1,035,000	117,000	1,214,000
Stop Sign	54,000	498,000	17,000	569,000
No controls	104,000	399,000	33,000	536,000
Others	21,000	129,000	10,000	160,000
Total	241,000	2,061,000	177,000	2,480,000
Pct %	10%	83%	7%	100%

Thus, Table 3 summarizes two-vehicle intersection/ intersection related crashes for their respective traffic control devices and leads into their crossing-paths.

Crossing-path Crashes

The two-vehicle intersection/ intersection-related crashes (2,061,000 crashes) from Table 3 are separated into their respective crossing-path crashes in Table 4. By definition, crossing-path-intersection-crashes are defined as the type of crashes where one moving vehicle cuts across the path of another, while they were approaching each other from either perpendicular directions, and collide at or near a junction. GES codes these attributes for each vehicle in the *Vehicle file*. However, Table 4 represents the traffic control device at the crash level which need not necessarily be the same at the vehicle level. These issues are addressed in the forthcoming chapters. The codes used in GES for the different crossing-path crash situations are given below:

1: Code 68-69 Left turn across path/Opposite direction (LTAP/OD)

- 2: Code 82-83 Left turn across path/Lateral direction (LTAP/LD)
- 3: Code 76-77 Left turn into path (LTIP)
- 4: Code 78-79 Right turn into path (RTIP)
- 5: Code 86-89 Straight crossing path (SCP)
- 6: Code 74,75,80,81,84,85,90,91 Other Crossing Path A pictorial representation of the graph is shown in Figure 3 [1]:

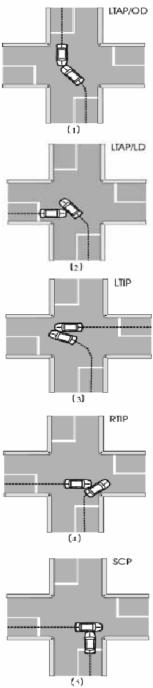


Figure 3. Descriptive diagram depicting the five crossing-paths: 1) LTAP/OD 2) LTAP/LD 3) LTIP 4) RTIP 5) SCP.

Table 4 summarizes the two-vehicle-intersection / intersection-related crashes and separates them between crossing-paths and non-crossing-path-crashes at intersections. It is seen that 1,114,000 (54%) of the two-vehicle intersection crashes are crossing-path crashes while 947,000(46%) involve non-crossing-path crashes like rear-end, lane-departure, side-wipe, backing etc., depicted by the shaded region. Also, other traffic control devices like yield signs, warning signs etc, are combined together as *Others*. This is shown in Table 4.

Table 4.
Distribution of two vehicle
intersection/intersection - related crossing-path
crashes for their traffic control devices including
'others/unknown'.

Two-vehicle					
intersection		Stop	No		
crashes	Colors	sign	Control	Others	Total
Crossing-path i	intersection	crashes			
LTAP/OD	207,000	10,000	72,000	16,000	305,000
LTIP	14,000	28,000	14,000	3,000	59,000
RTIP	20,000	27,000	6,000	4,000	57,000
LTAP/LD	47,000	105,000	18,000	8,000	178,000
SCP	139,000	205,000	20,000	24,000	388,000
Other CP crashes	53,000	40,000	26,000	9,000	127,000
Total	480,000	415,000	155,000	64,000	1,114,000
Non-crossing-p	ath two-veh	icle inter	section o	crashes	
Rear-end	447,000	55,000	155,000		705,000
Lane-change	45,000	2,000	28,000	6,000	82,000
Head-on	2,000	0	2,000	0	4,000
Side swipe/ Opp dir	2,000	1,000	4,000	0	7,000
Across path/ Same direction	27,000	4,000	36,000	3,000	70,000
Backing	14,000	11,000	5,000	3,000	33,000
Misc./ others	18,000	10,000	14,000	4,000	46,000
Total	555,000	82,000	244,000	65,000	947,000
Grand Total	1,035,000	498,000	399,000	129,000	2,061,000
	50%	24%	19%	6%	100%

Since the focus of this paper is on violations that lead to crossing-path crashes, two-vehicle non-crossing-path crashes are omitted from subsequent analysis. Also, crashes with *Other* type of traffic control devices are omitted as a means of simplifying the process. These are shown by the shaded regions in Table 4.

This leads to just two-vehicle intersection/ intersection-related crossing-path-crashes at traffic control devices of Signals, Stop Sign and No Controls as seen in Table 5. In Table 5, SCP crashes are the biggest contributors with 364,000(35%) crashes followed by LTAP/OD and LTAP/LD with 289,000(28%) and 170,000(16%) crashes respectively. This is followed by LTIP and RTIP each contributing to 56,000(5%) and 53,000(5%) crashes respectively. The rest of the 119,000(11%) crashes are *other crossing-path crashes* like left turn/right turn combinations, lane-keeping etc. This is seen in Table 5 below.

Table 5.
Distribution of intersection/ intersection-related crossing-path crashes based on their traffic control devices excluding 'others/ unknown'.

Crossing path	Colors	Stop Sign	No Controls	Total
LTAP/OD	207,000	10,000	72,000	289,000
LTIP	14,000	28,000	14,000	56,000
RTIP	20,000	27,000	6,000	53,000
LTAP/LD	47,000	105,000	18,000	170,000
SCP	139,000	205,000	20,000	364,000
Other CP crashes	53,000	40,000	26,000	119,000
Total	480,000	415,000	155,000	1,050,000
Pct%	46%	40%	14%	100%

Table 5 summarizes the basic combination of all twovehicle intersection/intersection-related-crossing-path crashes at traffic control devices of Signal, Stop Sign and No Controls.

2. Transformation Process

Table 5 presents the basic combination of the two-vehicle-crossing-path crashes at intersections. However, the challenges of identifying the violating vehicle, the appropriate traffic control device and the respective violation charged at the crash junction still prevails. These issues are addressed in detail in this section. The two key activities involved in the transformation processes are: 1) transformation of crashes to vehicles and 2) transformation of traffic control devices.

Transformation of crashes to vehicles: The key to an effective countermeasure system would be its ability to identify the violator or violating vehicle among a group of vehicles approaching each other at an intersection. Once identified, the system could warn or assist the violating driver of the impeding situation at the junction. This necessitates the inclusion of both vehicles in a two-vehicle crash. This is accomplished by moving the direction of the

analysis for the two-vehicle-crossing-path crashes from the *Accident /Crash level* to the *Vehicle level*. In order to better understand the situation, we examine the characteristics of the NASS/GES crash data files more closely. In GES, the *Accident file* contains information from 1988 to the current date on crash characteristics and environmental conditions at the time of the crash. There is one record per crash. The *Vehicle file* contains information describing the vehicles and drivers involved in the crash. There is one record per vehicle. The *Trafcon File* contains information of traffic control devices that govern each vehicle. It has one record for each traffic control

device and, at least one record for every vehicle.

Thus, the *vehicle file*, in combination with the *trafcon* file, assigns the traffic control device to each individual vehicle instead of the crash. The number of crashes in Table 5 is transformed in Table 6 to the number of vehicles involved in the crash. Thus, situations for Stop Sign /No Control combinations where This vehicle was at a No Control while the Other vehicle was at a Stop Sign, were both assigned a Stops Sign at the crash level. However, the vehicle file assigns the respective traffic control device to each vehicle for such situations. This results in the rearrangement in the estimates of crashes i.e. a decrease in crashes for Stop Signs (40% to 22%) in Table 5 and an increase in the number of vehicle for No control (14% to 32%) in the Table 6. Also, any combinations of known traffic controls (Signal, Stop Sign, No Control) for This vehicle with an Unknown traffic control for the other vehicle i.e. Stop Sign-Unknown or No-Control-unknown combinations were removed from further analysis. The result of these modifications is summarized in Table 6.

Table 6.
Distribution of vehicles involved in intersection/intersection-related crossingpath crashes based on their traffic control devices excluding 'other/unknowns'.

Crossing Path	Colors	Stop sign	No Control	Total
LTAP/OD	412,000	18,000	146,000	576,000
LTIP	29,000	29,000	52,000	110,000
RTIP	40,000	28,000	36,000	104,000
LTAP/LD	93,000	107,000	129,000	330,000
SCP	277,000	227,000	213,000	718,000
Other CP crashes	106,000	48,000	81,000	235,000
Total	956,000	458,000	657,000	2,071,000
Pct %	46%	22%	32%	100%

Transformation of Traffic control Devices: It is seen from Table 6 that intersections with signals account for 956,000(46%) of the vehicles in crashes and represent situations where both vehicles in either direction meet at a signal. Hence, the data for Colors represents both vehicles in that column and is consistent. However, the situation differs for Stop Signs and No controls. For situations with a Stop Sign/ No Control combination, i.e. situations where one vehicle is at a Stop Sign while the other vehicle is uncontrolled, the Vehicle file codes the traffic control of one vehicle to be at a Stop Sign while the other is coded to be at a No control. Thus one of the vehicles is represented by the 458,000(22%) vehicles at Stop Signs while the other vehicle is included in the 657,000(32%) vehicles at No controls. Also, situations where both vehicles are at a Stop Sign or No controls at an intersection are not separable from vehicles with Stop Sign/ No Control combinations in Table 6.

This necessitates the adjustment of the description of the traffic control devices at these junctions to adequately define the crash situation. The adjusted traffic control device for Signals, *Two-way Stop Sign*, Four-way Stop Sign, and No control is shown in Table 7. Thus, in the *Two-way Stop Sign* column, half of the 693,000 vehicles are at a Stop Sign while the other half are at a No Control. Both vehicles in the Four-way Stop Sign column are at a Stop Sign. Similarly, both vehicles in the No Control column are at an uncontrolled intersection.

From Table 7, it is seen that for vehicles at Signals, LTAP/OD and SCP were the major contributors for crossing-paths with 412,000(43%) and 277,000(29%) vehicles followed by (LTAP/LD) and (RTIP) with 93,000(10%) and 40,000(4%) vehicles. For vehicles at Two-way-Stop Signs, the major crossing-path types were SCP and LTAP/LD with 345,000(50%) and 187,000(27%) vehicles followed by contributions from LTIP and RTIP with 48,000 (7%) and 49,000 (7%) each. For vehicles at Four-way Stop Signs (except for LTAP/OD where the vehicles are in opposite directions), the biggest contributor was SCP with 55,000(50%) accounting for almost half of the crashes. This was followed by LTAP/OD and LTAP/LD with 16,000(14%) and 13,000(12%) vehicles. Small contributions were made from LTIP and RTIP with 6,000(3%) and 3,000(2%) vehicles. For vehicles at *No controls*, LTAP/OD is the biggest contributor with 144,000(46%) vehicles in crashes accounting for almost half of the crashes. This is followed by SCP and LTAP/LD with 40,000(13%) and 36,000(12%) vehicles. LTIP and RTIP

contributed to 28,000(9%) and 12,000(4%) of the vehicles.

Table 7.

Adjusted distribution for traffic control devices for vehicles in two-vehicle intersection/ intersection-related crossing- path crashes

Crossing Path	Signals	Two way stop sign	Four way stop sign	No Control	Total
LTAP/OD	412,000	4,000	16,000	144,000	576,000
LTIP	28,000	48,000	6,000	28,000	110,000
RTIP	40,000	49,000	3,000	12,000	104,000
LTAP/LD	93,000	187,000	13,000	36,000	329,000
SCP	277,000	345,000	55,000	40,000	717,000
other CP					
crashes	106,000	60,000	18,000	51,000	235,000
Total	956,000	693,000	111,000	311,000	2,071,000

Table 7 summarizes the vehicles involved in twovehicle intersection/ intersection-related crossingpath crashes. The remainder of the paper analyzes the role that violations play for the various types of crashes and types of traffic control devices.

Violations Charged

The NASS/GES data for violation is obtained either directly from an item on the Police Accident Report (PAR) or by interpreting the information provided in the report through reviewing the crash diagram, the officer's written summary of the crash, or combinations of variables on the PAR.

The variables used in GES to define the various violations are shown below:

Code 00: None

Code 01: Alcohol

Code 02: Drugs

Code 03: Speeding

Code 04: Reckless Driving

Code 05: Driving with a suspended or Revoked License

Code 06: Failure to Yield

Code 07: Running a Traffic Signal

Code 50: Hit and Run (No Information)

Code 97: Violation Charged- No details

Code 98: Other Violation

Table 8 introduces the types of violations that preceded these crashes at this point. The adjusted traffic control device and crossing-path from Table 7 are subdivided for their violations in Table 8.

For vehicles at *Signals*, 351,000 (37%) of the vehicles were cited for some kind of violation. Among them, *Failure to Yield* and *Red-light-running*

Table 8.

Distribution of vehicles involved in intersection/intersection-related crossing-path crashes based on traffic control devices at the intersection subdivided by cited violations.

Traffic	on traine control device						Other	
Control	¥72 - 1 - 42	I TA DOD	TTID	DTID	I TADIT D	CCD	CP	T-4-1
Device	Violation No Violation	256,000	19,000	RTIP	LTAP/LD		crashes 74,000	Total 606,000
	No Violation	,		25,000	57,000	175,000	,	ŕ
a	Alcohol and drugs	3,000	0	0	1,000	2,000	1,000	7,000
Signals	Speeding	1,000	0	0	1,000	1,000	1,000	4,000
	Reckless driving	0	0	1000	0	0	0	1,000
	Failure to Yield Right of way	73,000	1,000	4,000	3,000	4,000	4,000	89,000
	Running a red-light/ Stop Sign	11,000	3,000	2,000	15,000	48,000	2,000	81,000
	Hit and run	8,000	2,000	1,000	3,000	9,000	7,000	31,000
	Others/unknown	60,000	3,000	7,000	13,000	38,000	17,000	138,000
	Total	412,000	28,000	40,000	93,000	277,000	106,000	956,000
	No Violation	3,000	29,000	33,000	116,000	202,000	38,000	421,000
Two way	Alcohol and drugs	0	0	0	1,000	2,000	1,000	4,000
Stop Sign	Speeding	0	0	0	0	1,000	1,000	2,000
	Reckless driving	0	0	0	1,000	1,000	0	2,000
	Failure to Yield Right of way	0	10,000	8,000	41,000	69,000	6,000	134,000
	Running a red-light/ Stop Sign	0	1,000	1,000	3,000	24,000	2,000	31,000
	Hit and run	0	3,000	2,000	4,000	9,000	3,000	21,000
	Others/unknown	1,000	5,000	5,000	21,000	37,000	9,000	78,000
	Total	4,000	48,000	49,000	187,000	345,000	60,000	693,000
	No Violation	11,000	5,000	2,000	9,000	37,000	12,000	76,000
Four way	Alcohol and drugs	0	0	0	0	1,000	1,000	2,000
Stop Sign	Speeding	0	0	0	0	0	0	0
	Reckless driving	0	0	0	0	0	0	0
	Failure to Yield Right of way	2,000	0	1,000	1,000	4,000	1,000	9,000
	Running a red-light/ Stop Sign	0	0	0	1,000	5,000	0	6,000
	Hit and run	1,000	0	0	0	2,000	1,000	4,000
	Others/unknown	2,000	1,000	0	2,000	6,000	3,000	14,000
	Total	16,000	6,000	3,000	13,000	55,000	18,000	111,000
	No Violation	94,000	19,000	9,000	26,000	26,000	35,000	209,000
No	Alcohol and drugs	1,000	1,000	0	0	0	1,000	3,000
Controls	Speeding	1,000	0	0	0	0	1,000	2,000
	Reckless driving	0	0	0	0	1,000	0	1,000
	Failure to Yield Right of way	23,000	3,000	1,000	4,000	7,000	1,000	39,000
	Hit and run	4,000	1,000	0	1,000	1,000	3,000	10,000
	Others/unknown	21,000	4,000	2,000	5,000	5,000	10,000	47,000
	Total	144,000	28,000	12,000	36,000	40,000	51,000	311,000
	Grand Total	576,000	110,000	104,000	329,000	717,000	235,000	2,071,000

were the major contributors with 89,000(9%) and 82,000(8%) vehicles followed by *Hit and run* with 30,000(3%) vehicles. Vehicles not cited for any violations accounted for 605,000(63%) vehicles For vehicles at *Two-way-Stop Signs*, 272,000(39%) of the vehicles were cited for a violation. Among

them, Failure to Yield was the major contributor for cited violations with 134,000(19%) vehicles in crashes accounting for almost half of the cited violation followed by Running a Red-light and Hit and run with 31,000(4%) and 21,000(3%). Among them, 421,000(61%) of the vehicles were not cited for any violation. For vehicles at Four-way Stop

Signs (except for LTAP/OD where the vehicles are in opposite directions), only 21,000(19%) were cited for a violation. Failure to Yield was the major contributor for cited violations with 9,000(9%) vehicles in crashes followed by Red-light-running and Hit and run with 6,000(8%) and 4,000(4%). Among them, 76,000(68%) of the vehicles were not cited for any violation.

For vehicles at *No controls*, 103,000 (33%) of the vehicles were cited for some kind of a violation. *Others /unknown* violations was the biggest contributor with 47,000(15%) accounting for almost half of the know violations. This was followed by *Failure to Yield* with 39,000(6%) vehicles constituting the remaining half of the known violations. *Hit and run* accounted for 10,000(3%) of the vehicles in crashes. Vehicles not cited for a violation accounted for 209,000(67%) of the crash vehicles. The details of violations are shown in Table 8.

It is seen from Table 8 that types of violations have not been documented for 13% of the crashes and 63% of the vehicles have not been cited for a violation. This is because NASS/GES data is obtained either directly from an item on the PAR or by interpreting the information provided in the report through reviewing the crash diagram, the officer's written summary of the crash, or combinations of variables on the PAR. Because of this interpretation, and because the police officer may not have entered some item of information or provided complete information, data can be missing. Table 8 summarizes violations using the adjusted traffic control devices.

In order to better understand this and other aspects of the data, it is classified into three groups of two-vehicle crashes: 1) vehicles with *violation by neither* of the vehicles 2) vehicles with *violation by only one* of the vehicles and 3) vehicles with *violation by both* the vehicles. This is seen in Table 9 below.

Table 9.

Distribution of vehicles involved in intersection/intersection-related crossing-path crashes based on the number of vehicles cited by the GES codes for a violation.

	Crossing Path						Other CP	
	on Charged	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	crashes	Total
Violation by none of the vehicles					<u> </u>	1		
	Signals	142,000	12,000	15,000	30,000	98,000	49,000	346,000
tion	Two-way Stop Sign	2,000	13,000	20,000	59,000	89,000	19,000	202,000
No Violation	Four- way Stop Sign	7,000	4,000	2,000	6,000	22,000	8,000	49,000
Z	No Control	56,000	12,000	7,000	18,000	16,000	24,000	133,000
Total		207,000	41,000	44,000	113,000	225,000	100,000	730,000
Violatio	on by one of the vehicles							
No Viola	tion	156,000	32,000	26,000	95,000	215,000	58,000	582,000
Alcohol a	and drugs	4,000	0	0	2,000	4,000	3,000	13,000
Speeding	2	1,000	0	0	1,000	2,000	3,000	7,000
Reckless	driving	0	1,000	0	1,000	1,000	0	3,000
Failure t	o Yield Right of way	88,000	13,000	12,000	44,000	77,000	11,000	245,000
Running	a red-light/ Stop Sign	10,000	4,000	3,000	18,000	73,000	4,000	112,000
Hit and I	run	10,000	5,000	3,000	7,000	18,000	11,000	54,000
Others/u	ınknown	43,000	7,000	7,000	22,000	39,000	27,000	145,000
Total		312,000	62,000	51,000	190,000	429,000	117,000	1,161,000
Violation	n by both the vehicles							
Alcohol		1,000	1,000	0	0	1,000	0	3,000
and drug	-	0	0	0	-	0		2,000
Speeding		0	0	0	1,000	0	1,000	0
Reckless							-	-
	o Yield Right of way	11,000	1,000	1,000	4,000	8,000	1,000	26,000
	a Red-light/ Stop Sign	1,000	0	1,000	1,000	4,000	0	7,000
Hit and 1		3,000	0	1,000	1,000	3,000	3,000	11,000
Others/u	ınknown	41,000	5,000	6,000	20,000	47,000	12,000	131,000
Total		57,000	7,000	9,000	27,000	63,000	17,000	180,000
Grand T	'otal	576,000	110,000	104,000	330,000	717,000	234,000	2,071,000

It is seen that there were 730,000(35%) vehicles in crashes where neither of the vehicles were cited for a violation, 1,161,000(56%) vehicles were in crashes where only one of the vehicles was cited for a violation and 180,000(9%) vehicles in crashes where both vehicles were cited for a violation. The group where neither of the vehicles was cited for a violation was further classified for their traffic control signals. Among the 730,000 vehicles, 346,000(47%) of the vehicles were at a Signal and 133,000(18%) were at uncontrolled intersections. Among Stop Signs, 202,000(28%) were at a Two-way Stop Sign, 49,000 (7%) were at a Four-way Stop Sign. This is seen in Table 9.

Table 9 summarizes the separation of crashes based on the number of violations cited for pairs of vehicles. Independent of police citations, the logical assumption would be that there exists at least one violator in each of these intersection crash situations. This is illustrated with an example from the group violation by neither of the vehicles consisting of 730,000 crash vehicles. Among them, 346,000 of the vehicles were at signals. In actuality, at least one vehicle among the 346,000 vehicles in every one of these crashes should have been cited for a violation. Yet, none of them were cited for a violation. Similarly, for a SCP scenario at a Two-way Stop Sign, a two-vehicle-crash situation is the result of a violation by at least one of the vehicles. However, from Table 8, out of the 89,000 vehicles (45,000 crashes), neither of the vehicles were cited for any violation.

Table 8 and 9 establish the foundation for the classification and analysis of violations. The tables throw light on the apparent inconsistencies among violations and provide a basis for their consolidation.

3. Consolidation Process

The process developed in this paper to overcome the inconsistency is similar to the imputation process used by National Center for Statistics and Analysis (NCSA) where the data from the other/unknown categories are randomly distributed among the known data based on the percentage distribution of the unknown with respect to the known population.

The process accounts for violations by looking at combinations of pre-crash factors associated with vehicle pre-crash maneuvers and critical events and arrive at a conclusion about the crash dynamics. This provides more reasonable estimates of crash situations that could be addressed by appropriate countermeasure systems.

The process of assigning violations to crash vehicles uses some general guidelines based on the logical dynamic of the crash situation. These guidelines would support the basis of the assumptions to arrive at conclusive estimates for violations. The guidelines include all crossing-path crash scenarios under investigation and combine them with their respective violations and traffic control devices. The consolidation eliminates the need for Violation by neither of the vehicles group thereby providing a consistent set of violations by at least one vehicle. The details of the guidelines used for Red light running and Failure to Yield are given in the Appendix.

The challenge that prevails in the imputation process is the identification of the violator. Each scenario displays a unique dynamic between vehicles and hence requires a detailed inspection of violations. The process becomes even more difficult when none of the vehicles are cited for a violation at an intersection. For this purpose, the critical event variable and the pre-crash maneuver variable are used to arrive at conclusions about the violator. The key elements of the imputation process are: 1) Consolidation of types of violations 2) Consolidation of violations with type of crossing-paths.

Consolidation of types of violations: For violations, Red light running and Failure to Yield were considered as primary events for the intersection crash criteria. Alcohol and drugs, Speeding, Reckless driving and Hit and Run were considered to be preceding or precipitating events to these two primary violations. Each vehicle with one of these events was examined for their pre-crash maneuver and critical event. These events were cross-referenced with their respective crossing-paths and traffic control devices to identify possible Failure to yield or a Red light run violation for consolidation with the primary event. Combinations that did not meet the criteria were consolidated with Others. For e.g. Driving with a suspended license was not considered to be a related violation and hence was combined with Others.

Consolidation of violations with types of crossing -paths: Crossing-paths were also examined while assigning violations. For Straight paths, the focus of violation is only on the vehicle that is assigned the critical event of This vehicle crossing intersection. This is consistent with GES coding practice of having the initial critical event reflect the point of view of the causal vehicle. For Left turn paths, the violation is assigned to the vehicle with pre-event maneuver of turning and the critical event assigned to the vehicle

as This vehicle turning OR pre-event maneuver of going straight and the critical event assigned to the vehicle as This vehicle going straight. For Right-turn paths, the turning vehicle is assigned the violation unless the critical event is assigned elsewhere.

Vehicle speeds were also used in cases where the available information was not sufficient to describe the scenario. Conclusions from a previous study [9] showed that more than half of the red light runners were at a speed of 30 mph or less and the average speed was about 31.6. Based on the above conclusions, and certain assumptions made on vehicle dynamics, vehicles with speeds of greater that 25 mph and turning were cited for violations.

The consolidation process is further supported by a secondary extraction/validation process. In this process, the data is inspected for irregularities and inconsistencies that might have escaped the logical steps of the guidelines. Such situations were fixed manually by observing each scenario individually and correcting them when required. The process was repeated for each step of the consolidation process. The final data set showing the adjusted distribution of vehicles involved in intersection and intersectionrelated crossing-path crashes for their respective traffic control devices at the intersection subdivided by their violations is seen in Table 10.

It is seen that there were 956,000(46%) vehicles involved in crashes at Signals, 693,000(34%) vehicles at a Two-way Stop Sign, 111,000(5%) vehicles at a *Four-way Stop Sign*, and 311,000(15%) vehicles with No controls. Among Crossing-path crashes, SCP was the biggest contributors with 718,000(35%) vehicles followed by LTAP/OD and LTAP/LD with 576,000(28%) and 329,000(16%) vehicles. This is followed by vehicles at LTIP and RTIP each contributing to 110,000(5%) and 104,000(5%) vehicles.

For vehicles at Signals, the major contributors were LTAP/OD and SCP with 412,000(43%) and 277,000(29%) vehicles involved in crashes followed by LTAP/LD and RTIP with 93,000(10%) and 40,000(4%) vehicles. Also, 423,000(44%) of the vehicles were not cited for a violation. The major contributor for violation was Failure to yield with 266,000(28%) vehicles in crashes followed by Running a red light violation with 194,000(20%) vehicles involved in crashes. Other violations contributed to 73,000(8%) of the vehicles in crashes

For vehicles at Two way Stop Signs, SCP contributed 345,000(50%) vehicles while LTAP/LD

contributed to 187,000(27%) vehicles. RTIP and LTIP contributed to 49,000(7%) and 48,000(7%) vehicles. Among violations, 298,000 (43%) of the vehicles were cited for Failure to yield, which forms the majority of the violations. This is expected since a two way Stop Sign is a typical situation where one of the vehicle is controlled by a Stop Sign intending to go straight or turn (left/right) at the intersection while the other vehicle is on an uncontrolled roadway going straight. Running a Stop Sign contributes to only 31,000 (4%) of the crash vehicles. From previous studies [1] it is seen that people generally don't run Stop Sign and thus form a very small portion of the statistic. Other violations contributed to 39.000 (6%) of the vehicles.

Four-way Stop Signs are similar to Two-way Stop Sign, since a majority of them are Failure to yield cases where one of the vehicles does not stop long enough for the other vehicle to pass. Almost all of these crashes fall in the SCP scenario, which involve 55,000(50%) vehicles and contribute to half of the crossing-path crashes. This is followed by LTAP/OD and LTAP/LD which contribute to 16,000(14%) and 13,000(12%) of the vehicles in crashes. Also, Failure to yield is the major contributing violation with 49,000(44%) vehicles, accounting for almost half the crashes followed by Running a Stop Sign with 6,000(5%) vehicles. Other violations contributed to 6.000(5%) of the vehicles

For vehicles at No controls, the LTAP/OD is the biggest contributor with 144,000(46%) vehicles in crashes accounting for almost half of the crashes. This is followed by SCP and LTAP/LD with 40,000(13%) and 36,000(12%) vehicles. Also, Failure to Yield seems to be the major contributor of violations with 140,000(45%) vehicles constituting half of the violations. Other violations contributed to 23,000(7%) of the vehicles

Similarly, Table 11 provides the adjusted distribution of violating vehicles involved in intersection/ intersection-related crossing-path crashes grouped by the number of vehicles cited for a violation. It is seen that there are 1,891,000(91%) vehicles in crashes with at least one of the vehicles involving a violation and 180,000(9%) vehicles where both vehicles involved a violation.

Among violation by one of the vehicles, 693,000(37%) of them have a Failure to Yield violation while 182,000(10%) have a Running a red light violation. Also, 35,000(2%) of the vehicles had a Running a Stop Sign violation while 946,000(50%) of the vehicles were not assigned any violation at all.

For violation by both vehicles, 62,000(34%) of the vehicles had a Failure to Yield while 12,000(7%) of the vehicles had a Running a red light violation. Other violations contributed to 103,000 (57%) of the vehicles.

Table 10. Adjusted distribution of vehicles involved in intersection and intersection-related crossing-path crashes based on the traffic control devices at the intersection subdivided by violations.

Traffic control							Other CP	
Device	Violation	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	crashes	Total
	No Violation	185,000	13,000	18,000	42,000	126,000	39,000	423,000
Signals	Running a Red light	14,000	11,000	2,000	36,000	121,000	10,000	194,000
	Failure to yield	193,000	0	15,000	5,000	1,000	52,000	266,000
Device Signals Fwo-way Stop Sign Four-way Stop Sign	Others	20,000	4,000	5,000	10,000	29,000	5,000	73,000
	Total	412,000	28,000	40,000	93,000	277,000	106,000	956,000
	No Violation	2,000	23,000	23,000	87,000	159,000	31,000	325,000
Two-way	Running a Stop Sign	0	1,000	1,000	3,000	24,000	2,000	31,000
Stop Sign	Failure to yield	2,000	22,000	22,000	87,000	141,000	24,000	298,000
	Others	0	2,000	3,000	10,000	21,000	3,000	39,000
	Total	4,000	48,000	49,000	187,000	345,000	60,000	693,000
	No Violation	7,000	2,000	1,000	6,000	24,000	10,000	50,000
Four-way	Running a Stop Sign	0	0	0	1,000	5,000	0	6,000
Stop Sign	Failure to yield	8,000	3,000	2,000	5,000	24,000	7,000	49,000
	Others	1,000	1,000	0	1,000	2,000	39,000 10,000 52,000 5,000 106,000 31,000 2,000 24,000 3,000 60,000 10,000	6,000
	Total	16,000	6,000	3,000	13,000	55,000	18,000	111,000
	No Violation	66,000	13,000	6,000	17,000	18,000	29,000	149,000
	Failure to yield	72,000	12,000	4,000	17,000	19,000	15,000	139,000
	Others	6,000	3,000	2,000	2,000	3,000	7,000	23,000
	Total	144,000	28,000	12,000	36,000	40,000	51,000	311,000
Grand Total		576,000	110,000	104,000	329,000	717,000	235,000	2,071,000

Table 11. Adjusted distribution of vehicles involved in intersection/intersection-related crossing-path crashes based on the number of vehicles cited by the GES codes for a violation.

	Violation	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	Other CP crashes	Total
Violation by one of the vehicles	No Violation	260,000	50,000	48,000	152,000	328,000	108,000	946,000
	Running a red light	13,000	11,000	2,000	34,000	113,000	9,000	182,000
	Running a Stop Sign	0	1,000	1,000	4,000	27,000	2,000	35,000
	Failure to yield	247,000	36,000	40,000	107,000	168,000	95,000	693,000
	Others	0	4,000	4,000	5,000	19,000	3,000	35,000
	Total	520,000	102,000	95,000	302,000	655,000	217,000	1,891,000
Violation by both the vehicles	Running a red light	1,000	0	0	2,000	8,000	1,000	12,000
	Running a Stop Sign	0	0	0	0	2,000	0	2,000
	Failure to yield	30,000	1,000	3,000	8,000	17,000	3,000	62,000
	Others	26,000	6,000	6,000	17,000	36,000	13,000	103,000
	Total	57,000	7,000	9,000	27,000	63,000	17,000	180,000
	Grand Total	576,000	110,000	104,000	329,000	717,000	235,000	2,071,000

Table 10 and Table 11 summarize the adjusted violations for all vehicles involved in two-vehicle Intersection-related crossing-path crashes for their respective traffic control devices. The analysis provides a fundamental understating of crossing-path intersections and the violations associated with these junctions. Further analysis of driver factors like distraction and vision obstruction would help better understand the crash situation to provide adequate countermeasure systems at these junctions.

CONCLUSIONS

An analysis of violations associated with intersection crossing-path crashes was conducted using the 2004 GES data for the purpose of providing guidance for the CICAS-V project. The analysis was aimed at providing insight on the crossing-path problem. The results of the analysis may enable the authors and other interested parties with the ability to better ascertain and possibly devise appropriate collision avoidance countermeasures at such intersections. However, the recommendation of a particular countermeasure at this stage of research and analysis of crossing-path crashes would be premature. More statistical analysis including the all important Human Factors element must be incorporated into any potential countermeasure solution.

There were almost 1.1 million police reported twovehicle intersection-crossing-path crashes for the year 2004 which constituted about 17% of all crashes in the United States. All crashes occurred at an intersection or were intersection-related. The analysis was restricted to traffic control devices of Signals, Stop Signs and No Control.

Underlying concept of the analysis is that most crossing-path crashes involve either a Running a red light or Failure to yield type of violation. The paper was successful in addressing under-reported violations for pairs of vehicles and their interactions with each other at crossing-paths using pre-crash movement, critical event, and the type of traffic control device to identify the violating vehicle in each of these situations. This has resulted in a twofold increase in Red light running situations (81,000 to 194,000 vehicles) and a three-fold increase in Failure to Yield situations (271,000 to 755,000).

A summary of the findings of the analysis includes the following statements:

Vehicles at signalized intersections contributed the most number of crashes accounting for 956,000(46%) of the vehicles in crashes. Among them, Failure to Yield contributed to 267,000(28%) vehicles while Running a red light accounted for 194,000(20%) vehicles. This is followed by vehicles at Stop Signs with 803,000(39%).

Among Stop Signs, the crashes were distributed between Two-way Stop Signs and Four way Stop Signs. Two-way Stop Signs contributed to 693,000(86%) of the vehicles where the vehicles were at a Stop Sign /No Control combination. Among them, Failure to yield accounted for 298,000(43%) violations while Running a Stop Sign accounted for 31,000(4%) violations.

Crashes at Four-way Stop Signs contributed to 111,000(14%) vehicles where both vehicles were at a Stop Sign. Among them, Failure to yield accounted for 49,000(44%) violations while Running a Stop Sign accounted for 6,000(5%). Uncontrolled intersection contributed to 311,000(15%) vehicles. Among them, Failure to Yield accounted for 140,000(45%) of the violations.

Among crossing-paths, SCP crashes were the biggest contributors with 717,000(35%) vehicles followed by LTAP/OD and LTAP/LD with 576,000(28%) and 329,000(16%) vehicles. This is followed by vehicles at LTIP and RTIP each contributing to 110,000(5%) and 104,000(5%) vehicles. Other crossing-path crashes contributed to 235,000 (10%) of the vehicles.

Also, the analysis showed that among pairs of vehicles in crashes, 1,891,000(92%) of the vehicles had one vehicle cited for a violation. Among them, 693,000(37%) of the vehicles were cited for Failure to Yield while 182,000(10%) were cited for Running a red light. Running a Stop Sign contributed for 35,000(2%) of the vehicles. Also, 180,000(8%) of the vehicles were involved in crashes where both vehicles were cited for a violation. Among them Failure to Yield contributed to 62,000(34%) vehicles in crashes while Running a Red light contributed to 12,000(19%) vehicle.

ACRONYMS

PAR-Police Accident Report NASS- National Automotive Sampling System GES- General Estimating System CDS- Crashworthiness data system LTAP/OD- Left Turn across Path/ Opposite direction LTAP/LD-Left Turn across Path / Lateral direction LTIP-Left turn into path RTIP-Right turn into path SCP-Straight crossing-path

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APPENDIX

GUIDELINES FOR THE **EXTRACTION** PROCESS FOR VIOLATIONS

The guidelines provide details of the process used to consolidate violations at crossing-path by looking at combinations of vehicle pre-crash maneuvers and critical events for certain vehicle dynamics and arrive at a conclusion on the violator. The violations are classified between Running a red light and Failure to vield violations.

Running a Red Light

LTAP/OD

• If none of the vehicles were cited for a violation. then the onus of yielding falls on the turning vehicle since no information is available on the violating vehicle. Thus, if the vehicle was turning with a critical event of this vehicle turning and traveling at a speed greater that 25 mph at a signal, it was considered Running a red light.

Exception: the critical event could be due to the vehicle coming straight but is assigned to this vehicle.

• If at least one of the vehicles had a violation AND if a vehicle was cited for speeding or reckless driving or red light run, then cited for Running a red light.

- If none of the vehicles were cited for a violation AND the critical event on this vehicle was turning or going straight at a signal, it was considered a red light run.
- If at least one of the vehicles had a violation AND if the vehicle was turning or going straight with a critical event on this vehicle, OR cited for red light run or hit and run, then cited for Running a red light.

RTIP

• If at least one of the vehicles had a violation AND cited for red light run, then cited for Running a red light.

- If none of the vehicles were cited for a violation AND a critical event on this vehicle was turning or going straight at a signal, it was considered a red light run.
- If at least one of the vehicles had a violation AND if the vehicle was turning or going straight with a critical event on this vehicle, and cited for speeding or reckless driving or hit and run or red light run, then cited for Running a red light.

SCP

- If none of the vehicles were cited for a violation AND a critical event on this vehicle was going straight at a signal, it was considered a Red light run.
- If at least one of the vehicles had a violation and a critical event on this vehicle was going straight at a signal, then cited for Running a red light.

Other crossing-paths

- If none of the vehicles were cited for a violation AND if the vehicle was turning or going straight with a critical event on this vehicle and speed greater than 25, it was cited for Running a red light.
- If at least one of the vehicles had a violation AND if the vehicle cited for running a red light or hit run or vehicle was speeding or reckless driving while turning, then cited for Running a red light.

Failure to Yield

LTAP/OD

• If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND with a pre crash maneuver of turning and critical event of this vehicle turning or excessive speed or over the lane line OR critical event of this vehicle starting from a traffic lane, it was considered a Failure to vield.

Exception: the violation could be due to the vehicle coming straight but is still attributed to this vehicle, usually the turning vehicle.

• If at least one of the vehicles had a violation and at a Signal or Stop Sign or No Control AND with a critical event of this vehicle turning or going straight and some cited violation OR violation of Failure to Yield OR a critical event of this vehicle starting from a traffic lane, it was considered a Failure to yield.

- If none of the vehicles were cited for a violation and at a Stop Sign or No Control AND vehicle with a critical event of this vehicle turning or going straight, it was considered Failure to yield.
- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND vehicle with a critical event of this vehicle turning or going straight and cited for any violation, it was considered Failure to yield.

RTIP

• If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of this vehicle turning right, it was considered Failure to yield.

• If at least one of the vehicles had a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of this vehicle turning right or going straight and cited for any violation, it was considered Failure to yield.

- If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of this vehicle turning left or going straight or over the lane line, it was considered Failure to yield.
- If at least one of the vehicles had a violation and at a Signal or Stop Sign AND vehicle with a critical event of this vehicle turning left or going straight AND a violation of speeding or reckless driving or failure to yield OR vehicle turning right and cited for violation of hit and run or other violations, it was considered Failure to yield.

- If none of the vehicles were cited for a violation and at a Stop Sign or No Control AND vehicle with a critical event of this vehicle turning left or going straight, it was considered Failure to yield.
- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND vehicle with a critical event on this vehicle going straight and cited for some sort of violation, it was considered Failure to yield.

Other crossing-paths

- If none of the vehicles were cited for a violation and at a signal AND vehicle with critical event of this vehicle turning or going straight OR critical event NOT the other vehicle over the lane line OR crossing intersection OR Stop Sign or No Control OR vehicle with critical event of this vehicle turning OR poor road conditions or excessive speed OR pre crash maneuver was starting from a traffic lane, it was considered a Failure to Yield.
- If at least one of the vehicles had a violation and at a Signal- pre maneuver of turning left or a cited violation, it was considered Failure to yield.
- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND critical event of over the lane line or starting from the lane OR pre-crash maneuver of turning left with other/unknown violations, it was considered Failure to yield.

New requirements relating to the provision of assistance to road-accident victims: recent developments in France

Franck Batocchi, Céline Adalian PSA Peugeot Citroën, France Paper number 07-0306

ABSTRACT

In 2002, following the deaths of a number of firefighters attending road-accident scenes, the French Interior Minister Nicolas Sarkozy asked Colonel Pourny of the fire department to "conduct an analysis of the full range of missions carried out by firefighters and put forward proposals aimed at improving active and passive safety on the ground". In light of the recommendations of the "Pourny report", the French Directorate of Civil Defence and Security or DDSC (Direction de la Défense et de la Sécurité Civiles), decided to set up a joint working group with French car manufacturers. The group – which was set up in the spring of 2005 – was required to make improvements in the methods employed by teams working on damaged vehicles at accident scenes, the aim being to facilitate rescue work and enhance firefighter safety. Such improvement is vital given that recent vehicles (coupé-cabriolets in particular) are increasingly difficult to cut because of the reinforcements and impact-resistant materials used to protect passengers in the event of a collision. After a year's collaboration, the working group decided to focus on two complementary initiatives:

- The creation of an "extrication card" for distribution to French fire brigades;
- The organization of extrication exercises for active-service firefighters, using recent vehicles.

A detailed, illustrated presentation will be made of each of these initiatives, thereby raising awareness of the technical information contained in the extrication cards distributed to French firefighters since July 2006.

Details of pilot exercises will also be provided.

CONTEXT AND ISSUES

In 2002, following the deaths of a number of firefighters attending road-accident scenes, the French Interior Minister Nicolas Sarkozy asked Colonel Pourny of the fire department to "conduct an analysis of the full range of missions carried out by firefighters and put forward proposals aimed at

In his report, Colonel Pourny stressed that a better cooperation between the firefighters and the carmakers could change dramatically the

operations during road accidents in order to make them safer. The French Directorate of Civil Defence and Security or DDSC (*Direction de la Défense et de la Sécurité Civiles*) therefore took the lead of a new initiative.

A first high-level guideline meeting between the DDSC and the French car manufacturers was held early in 2005. In an extension of the Pourny report, the DDSC listed some initiatives to be undertaken for discussion with the car manufacturers. In the end, this meeting confirmed the commitment of the French car manufacturers to working with the various segments of French road emergency services to make progress in resolving the more and more frequently occurring problem of extricating people from new vehicles. In fact, there was more and more feedback from firefighters working in the field to emphasize how difficult, even dangerous, it is for rescuers to cut victims free from new vehicles which have been involved in accidents.

Although official statistics do not currently make it possible to specifically identify which accidents are linked to extrication operations, we have been able to observe, after careful analysis of the Ministry's accident analysis data for the year 2005, that 14 serious work accidents (person unable to work for at least one week) were probably caused by an operation to cut someone free from wreckage. It also emerged from this analysis that most injuries are caused to the hands (cuts, muscle / tendon / ligament wounds, crushing, amputation, etc.)

During this period, the most difficult vehicles to free people from according to the firefighters were the Peugeot 206 CC, the Renault Vel Satis and the Smart City Coupé. These three vehicles of the latest design, naturally praised for their excellent respective results in the Euro NCAP tests are in fact a representative sample of the new difficulties facing the firefighters: reinforced structures, metal inserts, innovative pyrotechnic devices, etc. All these new and effective systems used to save the occupants in a violent impact become the rescuers' enemies during rescue operations. The paradox is undeniable but unfortunately very real!

These reports really made French car manufacturers aware of the emergence of a new problem. They have already generally done excellent work in terms of protecting occupants in an accident (many vehicles scored 5 stars according to the Euro NCAP rating; Peugeot 1007 best score for occupant protection, all categories combined, Citroën C6 only car to obtain 4 stars in a pedestrian impact, etc.). However, the manufacturers are now certain that they have no option but to succeed in this "extrication" campaign.

The first real work session took place in the spring of the same year. The members of the working party met together round the same table for the first time. There were:

- 2 persons from the DDSC (Ministry of the Interior), responsible for managing the "extrication" initiative on behalf of the *Sous-Direction des Services de Secours* (Emergency Services Sub-Department);
- 2 persons from the Paris Fire Brigade (BSPP). The BSPP is an elite force reporting to the Ministry of Defence and its personnel are often called on for assistance in improvement schemes relating to the technical development of the work of firefighters in France;
- 1 person from the Essonne Service Départemental d'Incendie et de Secours (SDIS: regional Fire and Emergency Service). This experienced person, who is a specialist in extrication techniques, was and still is the principal instructor on this subject at the Ecole D'Incendie et de Secours (EDIS: Fire and Emergency School) in the Essonne département;
- 2 persons from PSA Peugeot Citroën, one of whom is the secondary safety (passive safety) department manager of the Group's Technical Department;
- 2 persons from Renault, holding the same posts as those from PSA Peugeot Citroën.

Of course, the composition of the working party would have to be modified from time to time, bringing in new skills or releasing others, but the main members listed above were always represented in the "hard core" and were among the most active.

The structure of the working party can be explained quite logically because it reflects the complex organization of the players at the French firefighters' level. Apart from Paris and Marseille, where the personnel report to the Ministry of Defence, fire brigades come under the authority of the *départements* within a body called the *Service Départemental d'Incendie et de Secours* (SDIS: regional fire and emergency service). These firefighters in the field are either full-time professionals or part-time volunteers from other trades. Their building facilities, vehicles, salaries, etc. are provided by the local authorities, the

regional councils, which naturally causes some disparity between rich *départements*, often industrialized with a high population density, and rural areas with less people. Laws governing the emergency services and the firefighters' profession, rules covering heavy equipment (communication, aircraft, etc.), training, etc. are placed under the responsibility of the *Direction de la Défense et de la Sécurité Civiles* (Directorate of Civil Defence and Security), reporting to the Ministry of the Interior, which thus ensures the overall cohesion of the whole system at national level.

EXTRICATION CARD: THEORETICAL ASPECT

Specifications and requirements

The group met several times during the year 2005 to specify exactly what is necessary on this extrication card. They decided that:

- only useful information should be shown.
- all the data should be contained in a singlesheet (double-sided) document.
- a template should be designed to ensure that every car manufacturer puts the same pieces of information in the same positions.
 - the template must use a colour-coded system.
- the template must use predefined pictograms and predefined terminology.
- the information presented on the extrication card should cover the maximum safety equipment and reinforcement available in this car model even though the vehicle could have standard or optional equipment.
- only if necessary (if the locations of the reinforcements or pyrotechnic devices are different) the different body types (5 doors, 3 doors, ...) will be shown on different extrication cards.

For these reasons, it was decided to define specific areas on the document for:

- a picture of the vehicle (7/8 left-hand front view).
- a key describing the colour codes and pictograms which must be used.
 - a CAD drawing of the seats and seat belts.
 - a CAD drawing of the car body in white.
 - a table showing the vehicle's fuel type.
- a table describing the pyrotechnic equipment designed for the driver, front passenger and rear passenger occupants.

- a space for comments: for additional information that cannot be put in the reserved spaces already described, including pictures if necessary..

Traceability

In order to ensure the extrication card is the latest version, the following traceability data are required at the bottom of each page:

- Make
- Model
- Body type(s)
- Year of launch
- Internal reference
- Date of creation
- Date of update
- Version No

Moreover, in order to control the traceability, only one PSA Peugeot Citroën department team is allowed to release the final documents and the updated documents each time its is necessary to amend an extrication card.

Accompanying documents

An instruction guide has been produced to explain what should be put in the various sections of the extrication card. This guide also shows examples for each predefined area. A table listing the latest version of each extrication card and its date of release is also available. This table is updated as soon as a new extrication card is issued or when an existing one is updated.

Extrication card layout

This template has been created so that the same card can be used for all models (irrespective of the car manufacturer). Thanks to this template, each piece of information will always be found in the same position. Figure 1 shows the key used in each extrication card.



Figure 1. Key showing the colour code and the predefined pictograms that will be used for all Extrication Cards.

For the same reason, it was decided to predefine the words used to describe the safety equipment (pyrotechnics) and their possible location (see Table 1).

Table 1. - Terminology used for all extrication cards – List of options for the occupant's pyrotechnic equipment

Pyrotechnic equipment	List of choice		
Front air bag	Steering wheel, Fascia,		
Front an bag	Seat belt		
Side oir bog	Seat Back, Seat Cushion,		
Side air bag	Door Trim Pad, Sleeper		
Curtain air bag	Roof, Seat back		
Knee air bag	Steering column, Fascia		
Seat cushion air bag	Seat cushion		
Rear impact protection	Seat back, Head restraint		
Seet helt mustangionen	Inertia reel, buckle, B-		
Seat belt pretensioner	pillar lower anchorage		

Description of the extrication card is given in Figures 2 and 3.

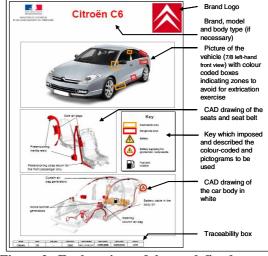


Figure 2. Explanations of the predefined areas on the 1st page of the Extrication Card.

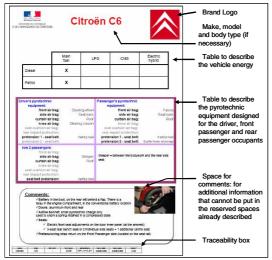


Figure 3. - Explanations of the predefined areas on the 2^{nd} page of the Extrication Card.

Note: Larger pictures of Figure 2 and Figure 3 are presented in Annex 1.

EXTRICATION CARD: PRACTICAL ASPECT

How do we create the cards? How can we ensure that the assessment of what is an "Inadvisable area" or a "Dangerous area" is correct? To answer these questions PSA Peugeot Citroën decided to create another step in the consultation with rescue teams by presenting the new car models and their extrication cards to a leading rescue team about three months before the launch.

The first step is to create a draft version of a new Extrication Card. In this draft version, we can create yellow boxes for structural zones which we do not know if current tools will cut (see Figure 4). We also make suggestions and give advice in the "comments" space.

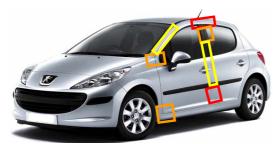


Figure 4. Draft version of the picture where the yellow boxes indicate the structural zones which we do not know if current tools will cut.

Then, we organize an "extrication day" with the principal rescue team. During this special day, we present the reinforcement and safety equipment of the new car model and the draft version of the extrication card. We also bring with us a crashed example of this new model.

The leading rescue team will examine the vehicle. They will carry out several extrication exercises on this car using different techniques as shown in Figure 5.

During this phase, PSA Peugeot Citroën safety experts will answer various questions and collect comments made by the team.

Following this practical exercise, to conclude this special event, a debriefing is conducted where the various zones of the structure are definitively described with the appropriate colour code and the necessary comments are put in the correct space.





Figure 5. Pictures of two different exercises carried out by the leading rescue team in order to validate the extrication card for a new model.



Figure 6. Final version of the Peugeot 207 extrication card (French version) where the yellow boxes have disappeared or been changed to orange boxes.

At this stage, the basic extrication card is then considered to be approved. The layout will be finalized by the engineers on their return to the design office and assigned a part number by PSA Peugeot Citroën.

PUBLICATION AND AVAILABILITY OF EXTRICATION CARDS

Campaign for France

The extrication card is then sent to the DDSC as a PDF file. When the file is received, the DDSC makes the card official for all French fire brigades by distributing it via a secure extranet site named "infosdis".

The "infosdis" information system then generates a special message to notify each SDIS that the new card is available. It is then up to each SDIS to download this information and update its information / training system: at the moment, extrication cards are usually included in a file which is then placed in roadside assistance vehicles.

This whole procedure was completed for the first time on 26 July 2006 for extrication cards for Peugeot and Citroën vehicles on the market at that time. It has since been repeated for the launch of three new vehicles (Citroën C4 Grand Picasso and Peugeot Expert / Citroën Jumpy) as well as for updating existing cards.

Campaign for other countries

The work carried out in France has made us aware of the requirements of emergency services in all the places where new vehicles, usually with high Euro NCAP scores, are marketed. After a survey carried out with our European subsidiaries, it has become apparent that most firefighters naturally encounter the same type of extrication problems as French firefighters, since the cars are the same in most European countries. Therefore, the decision was taken to have extrication cards of French origin translated into twenty languages in order to be able to distribute them via the Peugeot and Citroën subsidiaries established in those countries. This translation work was launched at the end of 2006 and the distribution of these extrication cards through our subsidiary companies is scheduled as soon as the translated versions are validated, i.e. during the first half of 2007. It should be mentioned that the translation work will be carried out by the PSA Peugeot Citroën Group after-sales technical departments, to ensure the correct technical quality and uniformity of terminology, as soon as the extrication card has been validated by the French fire brigades. By following this procedure in future, it should be possible to make extrication cards available in several languages, as soon as new vehicles are launched in the countries concerned.

CONCLUSION

We think that this extrication card initiative is an excellent example of successful action at the level of the integrated approach that many people are currently wanting in the area of road safety in Europe. In fact, more than ever before, the continued search for improvements carried on for many years to reduce the number of those killed and injured on the world's roads now evidently depends on concerted action on the following three major factors: the driver, the vehicle and the road environment with the various players, of which the fire brigades are in the front line. Thanks to this initiative, the firefighters are also at the centre of real concerns about our new vehicle projects in which the extrication card is a deliverable like any other.

This initiative is doubly praiseworthy because it is also part of a new field for motor vehicle manufacturers, a field that we at PSA Peugeot Citroën call "tertiary safety", which aims to find solutions for dealing with the aftermath of an

accident (in our jargon, primary safety aims to prevent the accident and secondary safety aims to protect the occupants and vulnerable users in an impact). After the successful deployment of our emergency call system, designed to give information about the occurrence of an accident, extrication cards are the second practical element our Group has contributed to the field of tertiary safety.

So, we hope that French firefighters, wherever they are, in the field, at the Ministry, in schools, etc. are as satisfied as we are with what has been achieved. Extrication cards will therefore be used with enormous benefit to road accident victims and those who come to their assistance. One of the objectives cited in the recommendations in the Pourny Report has therefore been fully implemented.

RECOMMENDATIONS AND THE FUTURE

It is clear that in future the number of vehicles on the European market receiving good or very good scores in the Euro NCAP tests (at least 4 or even 5 stars) will continue to rise. It is only a matter of time before all the motor vehicles on the road are replaced: in France, 50% of vehicles on the road are replaced in just over 7 years. The problems posed by the difficulty of cutting people free from wreckage will therefore logically become greater.

Of course, firefighters will work out new intervention tactics and their tools will be improved. The important thing, during this transition period, is for them to have the basic technical information required to compensate for this growing robustness of vehicles in order not to feel like they are going backwards, powerless. With the shared knowledge on the extrication cards, the motor vehicle manufacturers can help the firefighters to keep on making progress, while we and the experts in legislation and consumerism remain conscious of the fact that, in future we must take a more global view of car accident problems, in terms of a period during the event and a period afterwards.

With all the technological progress that the car industry is currently making, we also hope that one day we shall be able to make vehicles give details of their structure and restraint equipment at the same time as sounding the alarm and providing geo-localization information after an accident, thanks to a new generation of improved emergency call. Since progress is not confined to the motor vehicle industry, we also hope that this information could be made available in real time, with extrication cards already in the rescue vehicles. The project to refurbish the French Civil Protection

telecommunications system (Project Antarès), currently well under way, should one day make this possible. Then we shall achieve total integration.

ACKNOWLEDGMENTS

The authors would like to thank all those who have contributed to the success of the extrication card initiative, especially the following:

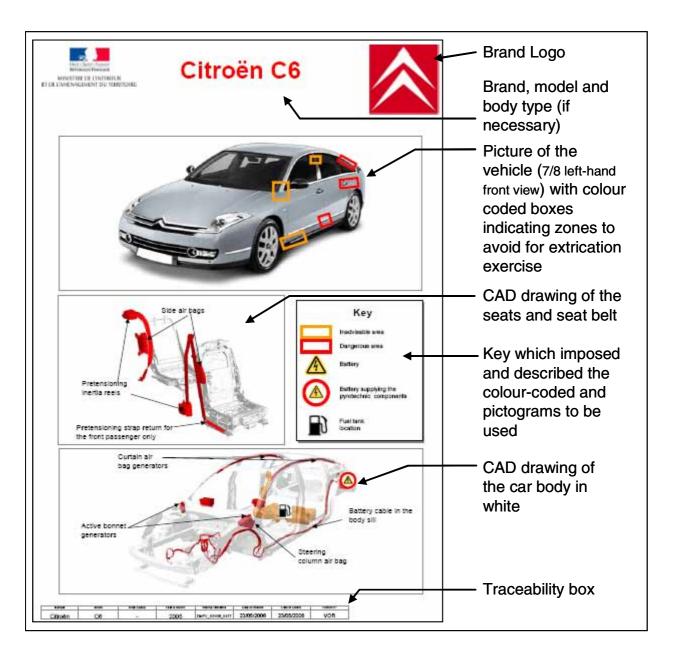
- DDSC: Philippe Deschamps, deputy assistant fire brigade manager and emergency service staff members, Colonels Sylvie Roques, Philippe Fleury and Gilles Berger, Captain Pagniez and Major Gérard Daveau;
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 - our colleagues at Renault;
- Monsieur Philippe Sion, Chairman and Deputy Leader of the Automobile and Motorcycle Importers Employers' Federation and Robert Muller of Volkswagen Group France.

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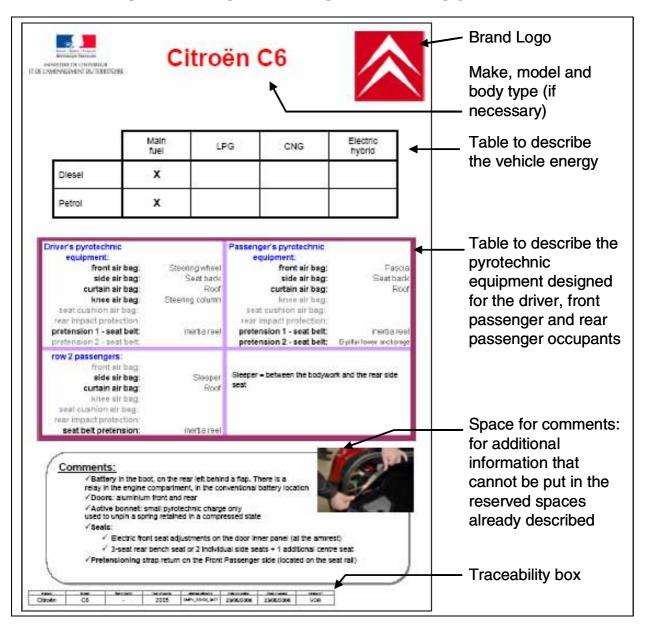
[1] Pourny Report

APPENDICES

Annex 1: Detailed explanations of the predefined areas presented on the 1st page of the Extrication Card.



Annex 2: Detailed explanations of the predefined areas presented on the 2nd page of the Extrication Card.



AUTOMATIC EMERGENCY CALLS IN FRANCE

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ABSTRACT

In Europe, during 2004, 1,7 million people were injured in road accidents and 43,500 were killed. Fast and effective care of polytraumatized people by the emergency services can reduce the number of those seriously injured and killed.

An automatic emergency call system has been installed on PSA passenger cars in France and in seven other European countries. It is an integrated car radio/GSM/GPS system that can be used with a SIM card. When an accident occurs, a call is sent automatically to a telephone call centre. Knowing the geographic location, the vehicle and owner identity and the possibility of communicating directly with the persons involved enables the nearest emergency services to be called out.

In this context, the LAB has set up a study aimed at evaluating the effectiveness of these systems. It consists of:

- an accident analysis study
- a questionnaire, sent to persons involved, aimed at estimating the time saved to get to the scene
- a judgement of the emotional reassurance brought to the vehicle occupants

During the system's first years of operation, about forty cases have been studied in detail, using accident analysis investigation procedures.

The initial findings show that pinpointing the exact accident location enables the emergency services to reach the scene very quickly. In addition, some important vehicles characteristics are transmitted to them. A future system improvement could be the calculation of the accident's severity, the impact type and the number of people involved.

The development of this automatic call equipment should continue in France and in Europe. It will be an additional tool in the fight against road injury and death, particularly for accidents at night, involving single vehicles and in isolated areas. The purpose of

this article is to explain the method of investigation used and present the first experimental feedback.

INTRODUCTION

For many years now, car manufacturers have devoted enormous efforts to improving the level of safety of their vehicles. These efforts have mainly concentrated along two complementary lines. The first line of action is that of primary safety, whose purpose is to prevent the accident from happening: here, visibility, braking, suspension, lights, etc. have been the main technical areas improved. The second line of action, secondary safety, is concerned with the protection of the vehicle's occupants during a traffic accident. For a few hundred milliseconds, according to an expertly programmed scenario, the structure of the vehicle, the seats, restraint equipment, airbags, etc. work together to reduce the consequences of the impact itself as far as possible. These two lines of action are still the ones receiving the most attention for safety reasons, but recently, solutions for responding to concerns about the post-accident period are emerging: the emergency call is at the forefront of tertiary safety.

GENERAL DESCRIPTION OF AN EMERGENCY CALL

The emergency call service is now available in nine western European countries on both Peugeot and Citroën ranges of passenger cars (except Peugeot 107 and Citroën C1) fitted with a telematic unit as standard or as an option. The procedure can be triggered manually or automatically.

Manual emergency call

In an emergency situation, the occupant of the vehicle presses the SOS button on the telematic terminal for at least two seconds. As soon as the button is pressed, the telematic terminal sends an SMS message to the IMA (*Inter Mutuelles Assistance*) centre assigned to cover the area in which the vehicle is located (Niort for France, Munich for Germany and Austria, etc.). This

SMS message contains vital information for dealing with the emergency:

- type and vehicle identification number of the vehicle, from which the vehicle type and specification, as well as the name of the owner, can be obtained;
- GSM telephone number;
- GPS coordinates of the vehicle;
- triggering mode: manual or automatic (airbag, seat belt pretensioners, etc.)

As soon as the call is intercepted, these details appear immediately on the IMA operator's control screen, in the form of a customer sheet, location on a digital map, etc. In this way, the IMA operator has useful data available even before establishing direct telephone voice contact with the occupant of the vehicle.

Once voice communication has been established with the driver, the IMA operator analyses the situation more closely. First of all, he ascertains whether the situation really is urgent. Then he analyses the situation (risk of death, number of persons involved, witnesses to the accident, etc.), he checks the location on various types of map, and if necessary informs the emergency services responsible for the area in which the vehicle is currently located (fire brigade, ambulance service, police, etc.), giving them all the information about the situation.

Depending on the situation, but only in France, the IMA operator can also call on one of the emergency doctors permanently stationed at the IMA centre, using a three-way conferencing system with a view to assessing the situation more accurately or to give advice while waiting for help to arrive. The three-way conferencing system can also be used to take care of people travelling outside their own country. Communication can be in their own language from the call centre in the relevant country, while the local public services will if necessary be informed in their own language by the national centre which covers the place of the accident.

At that stage the procedure continues "in the field" with the intervention of the emergency services at the scene of the accident until the people involved are taken care of definitively.

Automatic emergency call

After a violent impact, if the vehicle's pyrotechnic equipment has been triggered (airbag or seat belt pretensioner), the vehicle itself sends out the SMS message containing the basic information mentioned previously and the request for voice contact.

In all cases, if there is no response from the accident victim, the established protocol requires the IMA operator to try to make contact with the vehicle within a limited time: when the set time has elapsed, the operator must transmit the alert to the emergency services on the basis of the information contained in the SMS message: type of vehicle, owner's name, GSM telephone number, GPS coordinates of the vehicle.

Telematic platform development

The "Telematic Project" began at the end of the 1990s in the Group's own Direction Recherche et Innovation Automobile (motor vehicle research and innovation department) and finally in 2002 a working motor vehicle telematic platform was launched. Developed in partnership with Magneti Marelli, this equipment is in 1 DIN format, which corresponds to the standard size of a car radio. The care and attention given to the integration of various types of technology simplifies the work of designing the vehicle, enabling the equipment to occupy very little space on board (this technology usually requires 2 units). What is more, the deployment of the equipment across the range is facilitated because there is no variation: the equipment can be offered on all models, thus providing a means of access to the services connected to it.

Peugeot sells the product under the name of RT3 and Citroën calls it Navidrive. It provides a navigation system with on-board mapping, GPS satellite location module, GSM telephone module (900/1800Mhz), integrated voice recognition and synthesizer system (hands-free telephone kit, announcement of navigation instructions, voice command for main functions, etc.), and radio-CD.

Although it integrates all these technologies, in particular those relating to GPS and GSM, the terminal's telematic functions appear simply as two special very clearly marked buttons of different shapes on the front panel,:

- a red button, marked SOS, contacts the emergency call service, exclusively for emergency assistance to people;
- a button marked with the logo of the make of the vehicle contacts the commercial telephone call centre of Peugeot or Citroën, immediately able to provide the motorist with technical assistance services or help to continue their journey.

Setting up an efficient back office

In parallel with the engineering work to develop the in-car telematic platform, PSA Peugeot Citroën has set up a complete and efficient data processing system capable of providing the required emergency call service. This crucial task also required much work with several partners.

As soon as the emergency call is triggered, an SMS message is created and sent over the networks of existing mobile telephone companies by a first partner, an SMS aggregator. These SMS messages are sent via a unique subscriber number that all the companies have reserved, by means of an SMS gateway set up by the partner. The partner has a dedicated PSA Peugeot Citroën server used exclusively for handling the SMS messages concerning PSA Peugeot Citroën's localized emergency and assistance services.

These SMS messages are then decoded by means of an application specially developed for this function and hosted by a second partner, an *SSII Informatique*. Once decoded, the second partner immediately retransmits the data to the IMA via its own network.

The secure transmission and decoding tasks only take a fraction of a second.

At this point, the third and final partner comes into play in order to finalize the emergency call. Then the process of handling the emergency by the IMA operator mentioned earlier begins. Of course, the IMA operator makes use of modern telecommunications technology but also more importantly uses extremely valuable databases in order to ensure that appropriate action is taken (collection and updating of emergency numbers for areas where the service is offered). The expertise and experience of the IMA operator are very important here to ensure high-quality service.

LIVES AT STAKE

In 2005, road accidents killed nearly 1.2 million people around the World, of whom 45% were in Asian and Pacific countries (e.g. 100,000 in China and 90,000 in India) and 13% were in countries with high motor traffic density (43,000 in Europe, 42,000 in the United States, 8 500 in Japan). According to estimates, this represents 25 to 50 million injured persons.

According to a report published in 2005 by the World Health Organization, by 2020, the number of road accidents will have increased by 60%, especially in developing countries. Road accidents will then be the

3rd cause of death worldwide. In 1990, they were in 9^{th} position.

However, the latest statistics on traffic accidents in the 25 countries of Europe show a marked improvement with time between 1990 and 2004, in almost all countries except the Czech Republic, Cyprus, and Slovakia. The number of those killed annually in the European Union is now estimated at around 43,500 (cf. table 1). The most spectacular improvement was observed in France between 2001 and 2004, with a 32% drop in fatalities. The authorities attribute 75% of this decrease to the installation of automatic speedcontrol radar systems. The stakes are very high. Road accidents are the chief cause of death for 15-24-yearolds [ref. La sécurite routière en France¹]. In Europe during 2002, 1.7 million people were involved in accidents, of whom 220,000 were seriously injured and 39,000 were killed.

For France, that represents 116,000 persons involved in accidents, of whom 19,000 were seriously injured and 5,731 were dead within six days during 2003. In 2004, that figure was reduced to 5,217 persons who died within six days. France currently has nearly 30 million vehicles, which is one third more than ten years ago. But, during the same period the number of accidents has decreased by more than a third. At the same time, the number of deaths has fallen by 36.7%, the number of people seriously injured by 55.9% and the number slightly injured by 33.5%. There was a significant drop in the number of people killed in France in those two years: between 2002 and 2003, the decrease was 20% and between 2003 and 2004, 9%. Figures for the years 2003 and 2004 show a decrease never previously recorded.

Analysis of types of accident in France

France is one of the countries in Europe where the population density is relatively moderate compared with surrounding countries. It has approximately 110 inhabitants per km². More than 30 million vehicles travel on French roads, which make up a total of nearly one million kilometres. The road network consists of 1% motorways, 2.6% main roads, 36.1% secondary roads and 60.2% other roads and urban streets.

Table 1 below shows the distribution of traffic, the distribution of accidents and the distribution of people killed in France according to the type of road used. Note that the proportion of persons killed is greatest on secondary roads and smallest on motorways. The proportion of accidents on main and secondary roads

is 45% with a proportion of persons killed of more than 75%.

Table 1.
Distribution on French roads

	Mileage	Traffic	Accidents	Number killed
Motorways	1%	21.3%	6.3%	6.8%
Main Roads	2.6%	17.2%	14.2%	24.7%
Secondary Roads	36.1%	36.1%	30.7%	51.6%
Other	60.3%	25.4%	48.7%	16.9%

In 2005, police forces recorded 35,327 car accidents resulting in physical injury where no pedestrian or 2-wheeled vehicle was involved, including 5,847 on main roads and 12,392 on secondary roads. In addition, night accidents accounted for 37% of accidents resulting in physical injury involving at least one passenger car and 51% of accidents resulting in physical injury where a single passenger car was involved (figures 1 and 2).

Figure 1.
Day/night distribution of accidents resulting in physical injury involving at least one passenger car but no pedestrian or 2-wheeled vehicle (%)

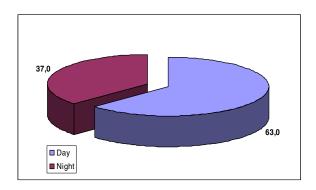
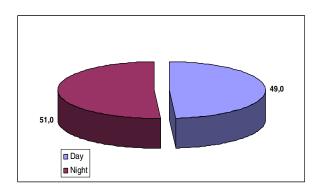


Figure 2.

Day/night distribution of accidents resulting in physical injury involving a single passenger car but no pedestrian or 2-wheeled vehicle (%)



With the same type of analysis, it appears that accidents involving passenger cars in rural areas account for 37% of accidents resulting in physical injury (figures 3 and 4) involving at least one vehicle and 50% of accidents resulting in physical injury involving a single vehicle. This means that 72% of deaths and 56% of serious injuries where a single vehicle is responsible occur out in the countryside. Also, 21% of deaths and 13% of serious injuries involve night accidents in rural areas with a single vehicle.

Figure 3.

Distribution according to road type for accidents resulting in physical injury involving at least one passenger car but no pedestrian or 2-wheeled vehicle (%)

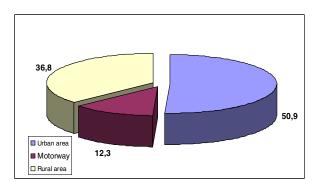
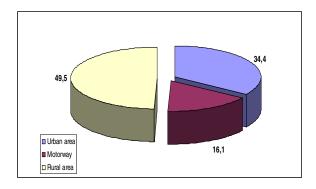


Figure 4. Distribution according to road type for accidents resulting in physical injury involving a single passenger car but no pedestrian or 2-wheeled vehicle (%)



The "rural area/night time/single vehicle" situation is the most difficult one for the emergency services to handle and the one where they are most likely to be delayed: problems of receiving the alert and locating the accident, difficulty of reaching the scene, etc... And it is often in these circumstances that the people involved must be cared for most quickly [ref. Chen⁶].

ACCIDENT ANALYSIS STUDIES

At the LAB, road accident analysis studies cover three areas: primary accident analysis, secondary accident analysis and tertiary accident analysis.

Primary accident analysis (pre-accident) studies active safety devices such as ABS (longitudinal control of the vehicle), emergency braking assistance, and ESP (lateral control of the vehicle). The aim is to provide and assess innovative car safety measures to prevent accidents.

Secondary accident analysis studies the consequences of road accidents. The aim is to provide systems for protecting the occupants in an impact. In this area, detailed investigations of crashed cars are carried out with the help of police forces, vehicle recovery specialists and emergency services. These investigations reveal the circumstances of the accident, allow measurements to be made on crashed vehicles and make it possible to obtain accurate assessments of occupants' injuries.

Lastly, tertiary accident analysis (post-accident) consists of optimizing the intervention of the emergency services after an accident - locating, taking care of the victims, information about the vehicle involved – to prevent the injuries of the victims becoming worse.

Secondary and tertiary accident analysis is based on studies carried out on selected accidents resulting in physical injury, following the general methodology used by the LAB for many years. The studies are carried out across the country on accidents selected for their value in terms of the development of safety systems. The following characteristics are selected:

- vehicles fitted with the latest passive and active safety equipment.
- cars carrying children.

These studies are carried out after accidents and selected from monthly files of traffic accidents supplied by the national police force: Traffic Accident Analysis Report or BAAC.

Initially, accidents are followed up by telephone, enabling researchers to identify accurately the vehicles involved and locate them at vehicle recovery and garage premises.

For each case the researchers must:

- obtain from the police all the information required to understand the accident: identity of the victims, diagram of the accident, location, weather conditions, environment, witness statements, photos taken at the time of the accident, etc.
- inspect the vehicles involved: take measurements of the deformation of impact zones and the passenger compartment; photograph the interior and exterior of the vehicle and details of zones struck by the occupants. Lastly, examine carefully restraint equipment such as seat belts, airbags and pretensioners.
- obtain medical reports on victims from hospitals: identification of each injury and its exact location, duration of hospitalization and time off work, etc.

These accident studies are then used to compile full accident files containing:

- summary of the information from the BAAC with the circumstances of the accident.
- vehicle data sheet and personal information sheet for each occupant.
- medical records with AIS levels.
- vehicle damage files with tables of measurements (EES, VR, DV, vehicle weight, extent of damage, intrusion, etc.).
- diagrams of the scene.

- comments on the accident and the structural behaviour of the vehicles.
- relevant photos with comments.

Three studies of accidents that occurred in rural areas at night, involving lone vehicles, illustrate the points noted above:

Example 1: at approximately 2 o'clock in the morning, the 47-year-old driver of the vehicle concerned loses control of his car on a left-hand bend on a narrow country road. The car leaves the road at low speed and slides down the bank (photos 1 and 2). It rolls over and ends up on its roof. The driver, shaken but not injured, very drunk, unfastens his safety belt with difficulty, falls onto the roof of his vehicle and goes to sleep waiting for the new day to dawn. It is the middle of winter and the temperature is -2°C. The driver of the vehicle spends the whole night in this position and is only discovered the next day around 11:30 a.m. in a state of hypothermia (body temperature 27°).

Photo 1.



Photo 2.



The driver died due to being exposed to a temperature lower than -2 degrees for more than 10 hours.

Example 2: During the night, for some unkown reason, a young man aged 22 goes off the road on a motorway. The weather is very cold (-9°C). The vehicle goes out of control, leaves the road on the right-hand side, jumps the embankment and goes down nearly 2.5 metres. It rolls over once or twice in the ditch, breaks the wire fence and comes to rest on top of it, on its wheels. The point where the vehicle fell is not visible from the roadway (photos 3 and 4).

The car is found by the emergency services in the morning around 8:15. The young man is curled up on his right side, on the driver's seat placed in the fully reclined position. In addition, he seems to have suffered from the night frost. His clothes bag, found the other side of the fence, suggests that the driver got out of his vehicle, then returned to it to take shelter and lie down.

According to the emergency services, the driver died a few hours after the accident. According to the autopsy, death appears to have been due to a haemorrhage in the pubic region and a fractured pelvis. Other injuries were observed such as a gash on the left temple, suggesting a head injury and a wound at the base of the neck on the left side.

Let us add finally that his mobile phone was found at the first point of impact, still in working order.

Photo 3.



Photo 4.



SETTING UP A SPECIAL STUDY

In this new context of the deployment of an automatic emergency call system, the LAB has set up a study to obtain experimental results about the system's operation and effectiveness and the feelings of people cared for by this means. This makes it possible to calculate the time saved in getting the emergency services to the scene and check the operation of the telecommunications systems and systems for locating the accident. It also provides realistic information about the perceptions of those involved. A special questionnaire [Appendix (1)] has been created for this study. It contains a score of very specific questions. The questions are in 3 sections:

- an accident analysis section to give details of the circumstances of the accident, place, time, number of occupants, injuries, how long the emergency services took to arrive, etc.
- a technical section to give information about how the system operated at the time of the accident, the communication between the people involved and the emergency centre, the telephone company used, etc.
- a section for the user/person involved to provide feedback.

First experimental results

In France between January 2004 and the middle of 2006, 270 automatic emergency calls were recorded. In the first few years of the system's operation, 41 calls from vehicles fitted with it have been studied in depth. As explained above, this study includes not only detailed information about the circumstances of the accident, but also accurate assessments of occupants' injuries and expert reports on the vehicles involved.

The first results, presented here, show that, by accurately locating the site of the accident, the system enables the emergency services to reach the scene very rapidly. The combination of GPS and the quality of current road maps is an essential tool. Another important point is that the emergency services can obtain the details of the vehicles on which they will have to work (type of vehicle and colour, type of fuel, vehicle configuration, etc.). Lastly, future development of the system should make it possible to assess the violence of the accident, the type of impact and the medical attention required. In addition this system reassures the victims and spares them additional stress, which is already very severe after the shock of the accident. Within a few seconds of the collision they know they are being taken care of and that the emergency services will be able to reach them very soon.

Examples of accidents

Several very different cases of cars fitted with an emergency call system are here presented:

The first sample accident, summarized in table 2, happened in Austria, on a minor mountain road covered with snow (photos 5 and 6). It well illustrates the value of the automatic emergency call system and how useful it is for the emergency services.

Table 2.

Place	In Austria, on a minor mountain road covered with snow.			
Time	Daytime.			
Circumstances	The vehicle concerned skids at low speed on a sloping bend, then leaves the road and falls down the bank. It ends up on its roof, jammed against a rock.			
Driver	Man aged 50, wearing seat belt.			
Front Passenger	Girl aged 13, wearing seat belt.			
Rear Passenger	Woman aged 51, not wearing seat belt.			
Help Given	Emergency call activated automatically. Emergency services arrived within ½ hour. Took care of both accidents.			
Injuries	Rear passenger injured with fractured collarbone.			

This case is all the more interesting because a second accident happened a few minutes later. Another driver arrives at the same bend and also loses control of his vehicle, which leaves the road and after flying through the air more than 15 m lands on its 4 wheels at the bottom of the bank a few metres from the first car. Injuries are slight and only the front passenger suffers compression of the lumbar vertebrae.

Photo 5.



Photo 6.



The accident was accurately located, in spite of the mountainous area. The emergency services were able to reach the scene quickly with suitable equipment for the weather conditions and the terrain. In addition, the reaction of the driver was excellent. He felt well cared for after this automatic call.

The second example, described in table 3, is an accident that occurred early in the morning on a motorway approximately 300 kilometres [180 miles] south of Paris.

The impact was violent (photos 7 and 8). There were no witnesses to the accident. Only a farmer, wondering what the noise was, came to help the driver. Although the driver had difficulty unfastening his seat belt (since he was upside down), the emergency call was immediately activated automatically.

After a brief conversation with the assistance centre and confirmation of the location of the accident, the emergency services were alerted. They arrived at the scene 10 minutes later.

Table 3.

Place	On a motorway about 300 kilometres south of Paris.			
Time	Very early morning.			
Circumstances	The vehicle arrives at the Chalon Sud exit slip road too fast and the driver is unable to negotiate the rather tight bend. The car crosses the central reservation, then the other carriageway, somersaults and ends up on its roof in the ditch.			
Driver	Man aged 50, wearing seat belt.			
Help Given	The emergency call was immediately activated automatically and the emergency services arrived at the scene within 10 minutes after the accident.			
Injuries	Minor injuries: grazes to the right hand and neck injury.			

Photo 7.



Photo 8.



The third example, described in table 4, was an accident in an urban area. To be specific, it was a front/side collision between a motorcycle and a car. The impact was very violent.

Table 4.

Place	Porte d'Orleans, Paris, along the ring road near the town of Montrouge.			
Time	Daytime.			
Circumstances	A motorcycle with an engine capacity of more than 600 cc coming from the Porte d'Orleans passes a first set of traffic lights at green and then the next set of traffic lights at red. Seeing that he is going to hit the car coming from his right, the motorcyclist drops to the ground and slides. He cannot avoid a collision. The motorcycle then strikes the car on the lower part of the front door and the rider strikes the lower part of the rear door and the wing. The impact is violent enough to trigger the left-hand side airbag and both the left-hand side windows explode in fragments.			
Driver	Man, wearing seat belt.			
Help Given	Emergency call activated immediately.			
Injuries	Car driver received small cuts to hands and thumb.			

The intrusion of the motorcycle into the left-hand front door of the vehicle is approximately 10 cm and the impact is strong enough to trigger the left-hand side and curtain airbags. The emergency call is activated immediately. The driver tries to open his door but it is jammed due to the collision and he receives the call from the assistance call centre. He describes the situation and confirms to the assistance call centre that the emergency services are needed. Several witnesses are present when the accident happens.

The driver was very pleased to have this device in his vehicle and being taken care of by the emergency services made him feel "safer".

The fourth example is described in table 5. This accident happened in a rural area, involving a car (photos 9 and 10) and a heavy construction vehicle. Once again, the driver of the people carrier was not seriously injured.

Table 5.

Place	On a straight stretch of minor road.			
Time	Daytime.			
Circumstances	Catches up with a civil engineering tractor and overtakes it. As the MPV driver comes alongside, the tractor driver suddenly turns left, blocking his path. The vehicle is struck on its right-hand front and then thrown to the left, ending up in the ditch.			
Driver	Man aged 63, wearing seat belt.			
Help Given	Emergency call activated automatically. Emergency services arrived within a quarter of an hour. Fire brigade took charge immediately. The driver left hospital 6 hours after the accident.			
Injuries	Minor injuries.			

Photo 9.



Photo 10.



The 5th example is a classic case, because the accident occurred on a country road in the middle of the night with a single car involved. In this case, while the 2 passengers in the vehicle are unconscious due to the impact, the voice of the emergency call centre operator wakes the driver from his blackout. The driver answers and confirms to the emergency call centre the need of assistance (table 6).

Table 6.

Place	On a minor road, at the exit from a roundabout.			
Time	At night.			
Circumstances	Accident in a rural area, 90 km/h (55 mph). Road with 2 single lanes. The 407 goes out of control at a roundabout, crosses the opposite lane, hits the kerb, then the bank, and rolls for a distance of about twenty metres.			
Driver	Man aged 21, wearing seat belt.			
Front Passenger	Man aged 21, wearing seat belt.			
Help Given	Emergency call activated automatically.			
Injuries	Driver: minor head injuries. Front passenger: seriously injured. Total injuries still unknown: fractured skull or neck?			

Photo (11)



The impact was extremely violent (photos 11, 12 and 13) resulted in the partial ejection of the passenger's head through the right-hand side window, causing serious injuries to his skull.

It is absolutely certain that the rapid arrival of the emergency services saved the passenger's head injuries from getting worse.

Photo 12.



Photo (13)



In the 6th example, the circumstances are very interesting because they demonstrate that the communication with the emergency call centre operator can come from a third party (for example a witness to the accident) and can be established from outside the vehicle (table 7). In this case, driving along a straight forest road, the left-hand front of the vehicle strikes a wild boar crossing the road. The impact is very slight because the dent in the car is only 12 cm with 10% of the front panel making contact (photos 14 and 15). No airbag is triggered. Only the seat belt pretensioners are activated, pressing the driver back in his seat to prepare him for a potentially more violent impact. However, the driver is in shock due to the minor impact and cannot answer the call of the emergency centre operator. Therefore, the lady driver of the car behind, who also witnessed the accident, answers the operator and takes over the conversation.

Table 7.

	T		
Place	On a straight stretch of minor road.		
Time	Daytime.		
Circumstances	The left-hand front of the 407 strikes a wild boar weighing about 45 kg. The driver says he was travelling at approximately 85 km/h (50 mph). Only the 2 front seat pyrotechnic pretensioners are triggered.		
Driver	Man aged 43, 1.82 m, 90 kg, wearing seat belt.		
Help Given	Emergency call activated automatically. Emergency services arrived within a quarter of an hour. Fire brigade took charge immediately. The driver left hospital 6 hours after the accident.		
Injuries	Neck injuries (pain, stiff back) and thoracic contusions near the sternum.		

Photo 14.



Photo 15.



Initial Technical Accident Analysis Conclusions

The following section gives a statistical overview of all the cases handled with Emergency Call. Note that in addition to the 41 cases of accidents dealt with in depth, 4 accident cases were handled without an Emergency Call. These accidents involved vehicles fitted with the system but where no call was made because there was no SIM card inserted in the terminal and therefore no communication established automatically with the emergency call centre.

Overall, for the cases studied, the degree of seriousness of the accidents was low. Only 1 fatal accident was recorded (killed in the vehicle that was struck) and 1 serious accident with only one person involved, at night in a rural area (see case described earlier).

The studies of these accidents already highlight some major statistical trends. First of all, table 8 shows the distribution between urban and rural areas for the accidents studied.

Table 8.

	urban area	rural area
Accident zone	51%	49%

Note that the distribution is almost the same as the distribution obtained from the national file.

If we identify more precisely the type of road on which the accidents occurred, we obtain the distribution in table 9.

Table 9.

	Road system on which the accident occurred		
Motorway	10%		
Main Road	5%		
Minor Road	36%		
Urban Area	49%		

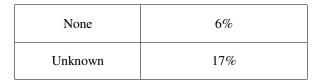
Note that 34% of people involved were alone at the time, but in 81% of cases, there were witnesses in the accident zone.

As far as the technical aspect of the emergency call system is concerned, in 100% of cases where those involved heard the call, the sound level of the system was loud enough and the people were able to answer, they were heard and there was no break in the telephone link. The telephone messages have always passed correctly whether French companies are used or foreign ones as in the case of the accident in Austria, which shows the strength of the SMS + voice solution. It appears that the area coverage is correct for the geographic locations of the accidents. In addition, although in some accidents the vehicle turned over and the roof aerial was torn off, no interruption in telephone communication was observed establishing communication between the person involved and the assistance call centre.

Table 10 lists the services involved after an accident. Note that in the majority of cases, the fire brigade and the police (very often both) went to the scene of the accident. Note also that nearly 11.5% of people concerned either did not call for any outside help or at most asked for their vehicle to be towed to a garage.

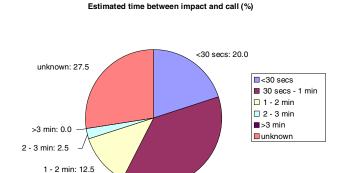
Table 10.

	Involved after an accident		
Fire Brigade	29%		
Ambulance	2%		
Police	40.5%		
Towing	5.5%		



For 21% of people involved, they estimated the average time between the impact and the call was less than 30 seconds and 34% estimated it was between 30 seconds and 1 minute. Figure 5 shows the total distribution.

Figure 5.

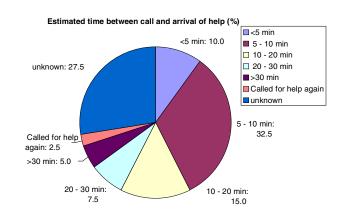


30 secs -

1 min: 37.5

If we move on to the average time for the emergency services to arrive as estimated by those involved, in 31% of cases it was between 5 and 10 minutes, and in 16% of cases between 10 and 20 minutes (figure 6).

Figure 6.



Lastly, it is important to mention that the feedback from those involved about the way the IMA took care of them was extremely positive in more than 85% of cases: listening, availability, presence, efficiency. Only 5 accident victims felt that the system did not help them at all in their case, either because the accident was too minor or because there were enough witnesses around to reassure them and alert the emergency services.

OUTLOOK AND CONCLUSIONS

The LAB estimates that it can complete a detailed study of about twenty emergency call cases per year on average. All these cases improve this new tertiary accident analysis database and thus it is hoped to have a statistically representative database available soon. This will then enable us to calculate more accurately how many lives such a system could save [ref. Clark¹²] [ref. Pieske¹¹].

By the end of October 2006, the service was operational in 9 European countries and more than 300,000 vehicles fitted with it have been sold in these countries. It now represents an additional weapon in the fight against road deaths and injuries, in particular for accidents at night in rural areas involving a single vehicle. As we have seen in a case described above, it is in these circumstances that the implementation of this system is expected to have the greatest benefits.

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APPENDIX 1: EMERGENCY CALL QUESTIONNAIRE

Did you know that your vehicle was fitted with an emergency call system?			Yes □	No □		
Did you insert a SIM card into the telematic terminal yourself?			Yes □	No □		
Which company do you use?	Orange □	Bouygues \square	SFR □	Other _		
Which type of SIM card do you use	2?		Subsci Pre-pa Dual	ription id	Mother □	□ □ Daughter □
Did you try to use the emergency c	all during your ac	ecident (pressing th	e SOS button	manually)?	Yes □	No □
Did someone call you in your vehic	cle shortly after th	ne accident?			Yes □	No □
Do you know which TELECOM co	ompany took care	of you?			Yes □	No □
		If so	o, company na	me		
Did you hear the words, "Hello, thi	s is Peugeot/Citro	oën Emergency"?			Yes □	No □
Could you hear the message clearly	7?				Yes □	No □
Were you able to answer?					Yes □	No □
Were you heard?					Yes □	No □
Was there any breakdown in the te	ephone connection	on?			Yes □	No □
If so, did someone make contact w	th you again a fe	w seconds after co	ntact was lost?		Yes □	No □
Did you feel you were being taken care of during the telephone contact?			Yes □	No □		
Did the time elapsed, between the initial accident impact and the telephone contact, seem long or short?			Short \square	Long □		
Can you estimate the length of time?					Yes □	No □
				Time		
Did you leave the vehicle immediately	after the accident?				Yes □	No □
If so, can you estimate how much time	later?					
Did you remember to remove the SI	M card inserted in	n your telematic ter	minal after the	accident?	Yes □	No □
		If	so, when?			
Were there any witnesses to the accide	nt nearby (homes, o	open countryside, etc	:.)?		Yes □	No □
Other details / 2 nd call:						
Estimated time taken for emergency se	rvices to arrive:					

TELEMATICS – THE ESSENTIAL CORNERSTONE OF GLOBAL VEHICLE AND TRAFFIC SAFETY

Peter Rieth

Recipient of the NHTSA award for "Safety Engineering Excellence", 19th ESV 2005 James Remfrey Ulrich Stählin Continental Automotive Systems Germany Paper Number 07-0360

ABSTRACT

The networking of active and passive safety (APIA) is the fundamental basis for comprehensive vehicle safety. Situation-relevant information relating to driver reactions, vehicle behaviour and traffic environment are fed into a crash probability calculator, which continually assesses the current crash risk and intervenes when necessary with appropriate measures to avoid a crash and reduce potential injuries. APIA provides effective protection not only for vehicle occupants but also for other, vulnerable road users. As this functionality up till now only relates to the vehicle itself, the next logical step is enhancement leading to the ultimate goal in safety performance, telematics. The integration of this embedded, invehicle wireless communication system allows Car-to-Car (C2C) and Car-to-Infrastructure (C2I) functionality for, e.g. hazard warning. This is an integral element of the cascaded Active Passive Integration Approach.

This paper describes the current status in the functional potential attained by networking active and passive safety systems (APIA) and introduces the next ultimate step towards global vehicle and traffic safety, telematics.

INTRODUCTION

It is still common practice to develop passive safety systems – which help mitigate crash-related injuries – as autonomous units, in a separate process from the development of active safety systems that help avoid crashes. The first decisive improvements in vehicle safety came in the mid-1960s with the introduction of the safety passenger cell, the three-point seat belt, and the optimized crumple zone – all focused on passive safety. With increasing numbers of ABS systems as standard equipment in the late 1980s, the foundations for active electronic safety systems (preventing the accident from happening) were laid.

Just how effective the networking of active vehicle safety systems can be, was first demonstrated by Continental in a primary phase in 2000, through the Reduced Stopping Distance (RSD) project. In what was called the "30-meter car", the tires, air springs, variable dampers and electro-hydraulic brakes were linked to form an optimized overall system. As a result, the car's braking distance from an initial speed of 100 kph was cut from 39 meters to 30 meters, and the total stopping distance was reduced by up to 13 meters, compared in each case with a standard production model.

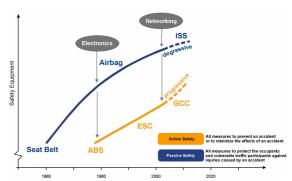
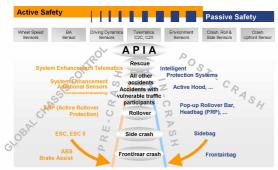


Figure 1. Zero fatalities Vision? Active safety to come.

Since then, important electronically controlled systems in both the active and passive safety areas have become standard specification in a broadbased vehicle population, systems such as ABS, ESC, belt tensioners, and airbags. These are, however, designed as stand-alone systems (Figure 1). Active and passive safety developments have remained two separate domains.

In order to attain optimum protection, however, these systems must be networked by collecting information on vehicle behaviour, vehicle environment, and driver reactions, merging the data, evaluating it, and translating it into coordinated protection measures.

Today, Continental's know-how in the fields of active and passive safety, innovative driver assistance systems, and tire technology is being channelled into the company-wide APIA (Active Passive Integration Approach) philosophy, in order to achieve a decisive step closer to the vision of a vehicle that can prevent crashes and mitigate injuries (Figure 2).



PRE-CRASH MEASURES close the Safety Gap!

Figure 2. Active Passive Integration Approach APIA.

Integrating active and passive safety

APIA brings together the vehicle's active and passive safety systems to form a network. The basic principle is the networking of the driving dynamics data supplied by the Electronic Stability Control ESC with the signals describing the driver's behaviour and the APIA's environmental sensors.

The key integration component of the APIA software is the crash probability calculator, which constantly processes and evaluates incoming data. For any given situation, the calculator computes a hazard potential that reflects the current crash probability.

Should the hazard potential exceed defined limits, the crash probability calculator initiates a function and time staged protection strategy (Figure 3). If, for example, two vehicles are driving nose to tail, various levels of crash probability and pre-crash protection measures can be determined from their relative speeds and the distance between them. Beginning with an acoustic, visual or haptic warning, these can extend from prophylactic (reversible) belt tensioning, adjustment of seat (anti-submarining), backrests and head restraints, to closing the windows and sunroof.

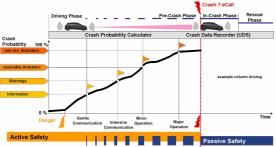


Figure 3. Crash Probability Calculator.

Simultaneously, the brake system is preconditioned by boosting the system pressure from pre-fill all the way to limited automatic pre-braking and extended brake assist function.

The full range of measures described above is only available if the vehicle is equipped with a full-power brake system including Electronic Stability Control ESC designed to accept external control signals and distance monitoring sensors such as those featured in ACC systems.

Sophisticated anti-lock brake systems with brake assist functions and adaptive cruise control systems give the driver greater and more comfortable control over the forward dynamics of the vehicle. Modern stability management systems such as ESC can now prevent many skid-related crashes. In addition, electronic control units for airbags, seat belts and rollover protection have significantly improved occupant protection over the last few years.

Advanced environmental sensors will play a key role in the development of the car of the future designed to prevent crashes and mitigate injuries. Continental has developed a pre-crash Closing Velocity (CV) sensor. This highly dynamic sensor, which features a wide short-distance detection range, is ideal for detecting events very near to the vehicle and enables precise predictions of the severity and direction of an impending crash. This information enables the crash probability calculator activate the multi-stage Smart Airbags appropriately. Apart from improving occupant protection, the CV sensor in combination with additional contact sensors mounted on the front end of the vehicle can also serve to enhance pedestrian protection.

For the short to mid-range vehicle environment, in addition to the existing radar and infrared sensors, Continental is currently working on the development of ISF – the Infrared Sensor Family. The sensors have the potential to cover both the short- and mid-range environment, so that APIA's active safety systems (preconditioning of the brake system, extended Brake Assist, ...) and passive safety systems (reversible occupant positioning and retention, vehicle interior preconditioning, Smart Airbags, ...) can be realized.

Another step towards greater safety will occur with the integration of image-processing camera systems. Continental is currently working intensively on such systems, which for the first time will be able not only to detect objects but also to classify them. The appropriate safety systems for a given situation can then be activated even more effectively, providing optimum protection for vehicle occupants and other road users.

Telematics integration

The "seeing" car of the future will feature onboard intelligence, data interchange with other vehicles, and telematics information, allowing it to actively avoid a large proportion of potential crashes (Figure 4).

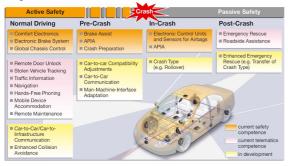


Figure 4. APIA-Functions.

With comprehensive vehicle safety and traffic management becoming more and more critical aspects of global mobility, the essential cornerstone Telematics will play an important role in efforts to integrate embedded, in-vehicle wireless communication systems into our Active Passive Integration Approach (APIA), which focuses on creating cars that avoid crashes, prevent injuries and provide immediate assistance if a crash proves unavoidable.

Telematics - eCall

Continental's Telematics systems help to make cars safer and provide a "wireless life-line" to emergency assistance the critical seconds after a crash occurs. In case of an accident, the eCall Telematics Control Unit (TCU) in the car will transmit an emergency call that is automatically directed to the nearest emergency service. eCall can be triggered in two ways. Manually operated, the voice call enables the vehicle occupants to communicate with the trained eCall operator. At the same time, a minimum set of data will be sent to the eCall operator receiving the voice call.

In case of a severe accident the information on deployment of e.g. airbags or in-vehicle sensors will initiate an automatic emergency call. When activated, the in vehicle eCall device will establish an emergency call carrying both voice and data directly to the nearest emergency services (normally the nearest 112 Public Safety Answering Point, PSAP).

The life-saving feature of eCall is the accurate information it provides on the location of the accident site: the emergency services are notified immediately, and they know exactly where to go. This results in a drastic reduction in the rescue time.

Estimations for eCall carried within the E-MERGE project and the SEiSS study indicate that in EU-25 up to 2.500 lives can be saved per year, with up to 15 % reduction in the severity of injuries.

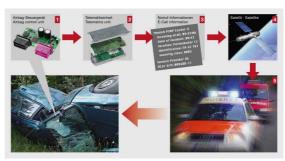


Figure 5. eCall - Rescue Chain.

Telematics – Car-to-Car (C2C) and Car-to-Infrastructure (C2I) Communication

Under development is Dedicated Short Range Communication (DSRC) for vehicles, which allows receiving of traffic and warning information directly from other cars, even those not visible to today's environmental sensors. Examples for DSRC applications are shown in the following. (Figures 6 to 9)

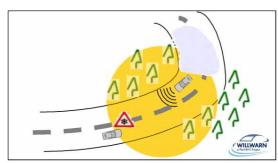


Figure 6. Hazard Warning.

Hazard Warning

The driver is warned if his vehicle approaches a potentially hazardous situation on the road ahead. Hazards can be construction zones, breakdown situations, accidents, end of traffic jams, imminent forward collision, black ice, etc.

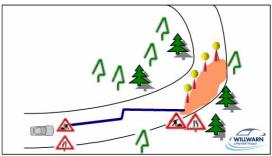


Figure 7. In Vehicle Signing.

In Vehicle Signing

Display or announcement of localized traffic sign information such as speed limits, temporary right of way changes, traffic routing, etc. It is of particular relevance for, but not limited to, dynamic information.

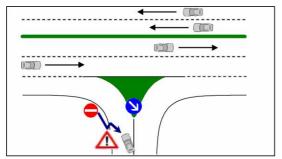


Figure 8. Traffic Rule Violation Warning.

Traffic Rule Violation Warning

The driver is warned if he is about to violate a traffic rule. This includes traffic signal violations, stop sign violations, right-of-way violation and cross-traffic collision avoidance, etc. It is of particular relevance for, but not limited to, dynamic traffic sign information.

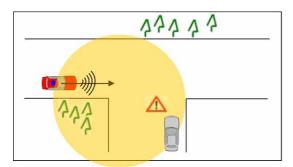


Figure 9. Emergency Vehicle Warning.

Emergency Vehicle Warning

The driver is warned of approaching emergency vehicles which claim the right of way.

Shadowing by other vehicles, as with environmental sensors, will be less of a problem and therefore further increase the range achieved in typical driving situations. In addition, information from the infrastructure can be provided, such as traffic light status, position of road works, local weather information, etc. DSRC will reduce the driving risk by providing local hazard warnings and bring active safety to a new dimension.

Combining DSRC and environmental sensors will lead to cascaded information and actions resulting

in a system capable of providing a safe driving state, helping to prevent crashes and in case needed reduce the severity of a crash. Therefore, the information from DSRC is taken into account first, validated via environmental sensors and accordingly supported by actions such as provided by ESC systems.

Telematics – Connectivity

On the comfort side this next generation of telematics systems will soon offer the motorist even greater freedom at the wheel. Any portable device connected to the vehicle by Bluetooth or USB can be operated either by voice command or from the controls in the steering wheel or instrument panel. In addition, the new telematics systems use wireless connectivity to load address books from the cell phone into the car; they can read out incoming short messages and support personalized ringtones and stored speed dialling numbers. An optional, integral telephone module allows both internet access and service and functions, including assistance automatic emergency calls.

CONCLUSION

Today's vehicles have already reached a high safety standard thanks to current, state of the art technologies such as Airbags and the Electronic Stability Control System ESC. Networked active and passive safety is starting to be equipped to premium class vehicles and will be enhanced by telematics – in this case by eCall. But telematics also offers possibilities for safety related vehicle communication in the future, namely C2C and C2I. The information cascade for safety systems improves the range of APIA. Cascading starts with DSRC, is validated by environmental sensors and the performed actions are supported electronically controlled safety systems e.g. ESC. Telematics integrated together with APIA offers comprehensive traffic safety and can be combined with service providers with the aim to provide intelligent mobility.

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BLACKBOX - PROJEKT V&V MD ČR

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ABSTRACT

The authors of this paper would like to introduce the results of the National Research Project Ministry of Transport CR called BlackBox.

Project goal is to integrate functions of vehicle's monitoring behaviour pre-crash, during crash and post-crash to the current or developed motor vehicles systems, for the purpose:

- •Create an instrument for support to make clear specific road traffic accident (chain accident, etc.);
- •Make easer the guilty and innocence clarification;
- •Make easer the process of insurance event liquidation;
- •Increase the active safety (psychological subconscious of driver about the possibility to documentation behaviour of vehicle);
- •Increase the process of legislation to embed system in vehicles;

(e.g. in police, fire brigade vehicles, driver's school);

Participants of the project: Transport Research Centre, e4t electronics for transportation, Brno University of Technology Faculty of Civil Engineering. Project is solved in cooperation with experts of Department of Forensic Engineering, Traffic Police, Insurance Companies etc.

HISTORY

The Black Box units for motor vehicles were firstly planned in early seventies, when the USA Nation Bureau for Road – Traffic Safety started using device, which was able to workout the analog signal and was able to save gained data.

In 1974 were thousand cars equipped by this device. Therefore it covered many groups of drivers. Thanks to this device the analysis of many accidents was possible and it recorded whole process of deceleration of the vehicle, especially Δv . During this year General Motors introduced airbag system in several model lines. There was implemented a special unit whose main characteristic was a data collection and its evaluation whether the airbag should have been activated.

In 1976 GM introduced SDM module (Sensing and Diagnostic Module), which was improved to so called DERM (Diagnostic and Energy Reserve Module) in 1990. The main target of this module consists of recording and saving data from measuring sensors including error messages at the time when the airbag is activated. In 1990 GM installed the first sophisticated electronic accident data recorder in F1 cars.

As it is clear from the article above, firstly the mentioned units were designed as a diagnostic tool for a determination of the reasons for the airbag activation. Later, units were used for accident reconstructions. It was asked by insurance companies and police.

In 1992, thanks to the co-operation of Great Britain, the Netherlands and Belgium the European project called SAMOVAR (Safety Assessment Monitoring on Vehicle with Automatic Recording) came into existence. This project is targeted on motor cars monitoring by black boxes and its possibilities to improve road – traffic safety.

During years, there were more attempts of some alternatives of the black box but it was not widespread used.

CURRENT STATUS

Nowadays, it is not obligatory to use Black box car units in the car in the Czech Republic. This project should make the next step to standardize using of this unit by law. It is possible to image using of these units in cars with higher risk (police, taxi, ambulance etc.).

Association for the advancement of technology (IEEE-SA) started working on P1616 project, concerning implementation of a universal standard of a black box for motor cars. The black box should be called MVEDR - Motor Vehicle Event Data Recorder - and it should work like the same unit in airplanes. This device is being developed for usage in all types of motor cars used in the road transportation. MVEDR project standardizes and defines how the data will be gained, recorded and transferred. The next thing that is mentioned by MVEDR is how these data as date, time, place, speed, number of passengers etc. will be recorded. These data could be used for better development of the passive – safety systems.

Within UNECE (United Nations Economic Commission for Europe), there were proposals from the French expert concerning the standardization study of an events data recorder (EDR)

GRSG group within WP.29 asked for cooperation on the international accident data recorder.

We should thing about the topic, why the current units are not used, nowadays. We can see the answer in three main areas: there is no legislative support; units are not implemented to the car; no support for data analysis.

THE BLACK BOX STUDY PROVES ACCIDENT DECREASE

The human behavior is the main factor for the road – traffic safety. Concerning this reason it is very important to motivate people to behave on road more responsible. Following and recording of a driver's behavior could lead to confrontation with the driver's statement, later. It means that drivers, who are aware of this, change their behavior before the accident happen. This should lead to decrease of road accidents.

In 1992, the project SAMOVAR (Safety Assessment Monitoring on Vehicle with Automatic Recording) took place in Europe. Great Britain, the Netherlands and Belgium took part in this project. SAMOVAR project worked also within 'DRIVE 2' project.

It was targeted on cheap electronic systems for recording car data and its communication with other systems and databases. SAMOVAR system included a central interface, which integrated several subsystems used by car or the fleet manager. The complete subsystem included these functions:

- Monitoring and recording of parameters of the car's systems
- The dangerous car, driving or surroundings warning
- Advise driver's position, trip and other information
- Detect and record details about the accident

Within SAMOVAR project the Dutch national road safety research institute (SWOV) made a study No.R-97-8. The main target of this study was to find out whether the road – traffic safeness could be increased by driver's confrontation with objective data and his/her own behavior recorded by telematics device in the car. There were 270 cars with this device included in the study. This devices concerned 'accident reconstruction recorders', 'trip recorders' or 'journey recorders'.

The accident data included in the study were recorded within one year period before and after implementation of the device.

This study showed a big reduction of accidents of different fleets, whose driver's behavior was monitored. The calculated result is that there was 20% decrease of accidents in these fleets.

In SAMOVAR project was monitored 850 cars within one year period. The result was 28% accident decrease and 40% decrease of expenditures spends on repairs.

The following table (tab.1) proves this fact. Companies using black boxes are mentioned in this table. (Source Siemens VDO – Automotive)

Table 1.

Decrease of accidents within one year period while fleets use Black box

	Accident decrease	Expenditures decrease
SAMOVAR	-28 %	-40 %
WKD Security	-30 %	-
Vienna police	-18 %-	-40 %
Suedbaden Bus Co.	-18 %-	-59 %
Taxi Hatscher	-66 %-	-
Berlin police	-20 %	-25 %
Border police	-9 %	-34 %
Rotterdam police	-	-25 %
London met. police	-25 %	-

SYSTEM PROPOSAL

Demands on unit

It is possible to divide demands on unit into two categories: technical and economical. Technical part has to provide collecting of relevant data (speed, lights, current position, etc.), its verification and later objective processing. Using of data from the CAN – BUS supplement by other measured parameters is presumed. It is important to reach the lowest expenditures from the economical point of view and to keep the widest spectrum of functions. This philosophy is fulfilled by integrating as much function as possible to current car unit. This solution should reduce duplicate HW features (GPS system, CAN, display...), makes the process of implementation to the car easier and make the same thing during tests and certification.

The recorder that we proposed count on optional implementation to car categories: personal car, lorry car, bus that have CAN – BUS. The implementation to other cars without CAN – BUS is also possible but it needs installation of autonomous sensors. The system takes data from the CAN – BUS periodically. The system analyses data and writes them to the cyclical buffer. When is buffer full, data are re-written. This process is stopped when the accident is detected. This is decided when some specific limits are exceeded. The following criteria were important when we proposed parameters for recording in Black Box unit:

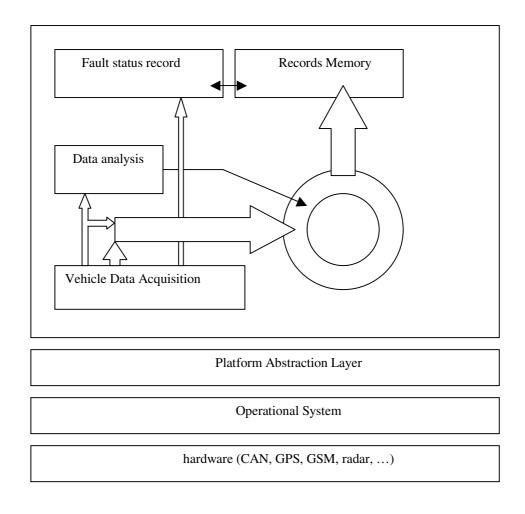
- Information accessible on CAN BUS
- Architecture of the current car systems with perspective of their further development

- Proposed standards (USA)
- SW compatibility with the current products on the market designated for analysis of recorded data
- Suggestions and recommendations of Škoda Auto developers, experts of Institute of Forensic Engineering, etc.

The proposal supposes a record about the accident in the length of 90s (60s before collision and 30s after collision. It should be possible to record 810 s when the collision is multiphase).

Figure 1.

Internal architecture of the application for data recording



NEW DIRECTIONS IN THE TRAFFIC ACCIDENTS' RESEARCH

There will be possible to find stimulation for analysis and improvement of active safety on the model construction "driver-car-external circumstances" for both human and technical factor. The active safety has to be understood in context of other features. It depends on each accident's individual conditions and there

are specific questions about reasons and ways how the accident has arisen. For example if there is a stack-up on the highway there are some important questions:

- Was the intention of changing the line advised on time and was the direction light used?
- Were the following cars warned on time by switching on the warning lights?
- Did other cars use any type of warning?
- Is there also reason for accident like driver's fault with following high side acceleration?
- Was the process of the accident influenced by side wind?
- Was the car stability influenced by road defects?
- Was the car's brake potential fully used?
- Were other brake or avoidance maneuvers done?
- How big were distances between vehicles and their speed before accident? What was the time interval between collisions of vehicles?

Providing, that all cars taking part in the accident would content Black box, we could answer these questions exactly, thanks to recorded data.

Black box opens new possibilities and perspectives of the traffic accident research. It concerns results of analysis which provide optimalization of existing safety conceptions in vehicles constructions or new technical features (driving assistant, braking assistant). The substantial thing is that in contrary to tests and controlled driving tests, it is possible to analyze real reactions evoked by subjective feelings, fear and panic. We can gain data not only about behavior of normal driver but also about things diverge from standard.

The driver – dynamic mathematic model was developed in the end of 80's for analyzing drivers' behavior within situation leading to an accident. The combination of these factors should have been analyzing using the model mentioned above. Better description and research of characteristic maneuvers was wrecked because of lack of data and its low quality. Data did not give us enough information about behavior of the driver/car model when danger occurs before collision. Black box unit is able to provide these data in good quality and reliability.

ENHANCING FUTURE AUTOMOTIVE SAFETY WITH PLASTICS

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ABSTRACT

A revolution in automotive technology is underway globally. Automobiles of the 21st century will feature radically improved safety and sustainability attributes. Safety R&D is embracing active and passive systems, and advanced vehicle propulsion R&D is tackling cleaner, more reliable energy sources. The innovations currently under development across multiple transportation venues including aerospace have the potential to alter automotive vehicle designs and supporting infrastructures around the globe by 2025.

These revolutionary changes suggest a critical need to rethink vehicle architecture and materials requirements. Versatile, durable, and lightweight plastics, plastic composites and plastic-metal hybrid materials that increase the efficiency, crashworthiness, and functionality of today's vehicles hold immense potential to radically enable and optimize advanced vehicle technologies for the future. An important step was taken in this direction in 2002 when the Plastics Division of the American Chemistry Council (ACCPD) then known as the American Plastics Council, published *Plastics in Automotive Markets—Vision and Technology Roadmap*¹ to help define this potential.

Recognizing this need and building on Plastics in Automotive Markets, ACCPD sponsored a Technology Integration Workshop in November 2005 to begin exploring the full potential of polymer-based materials to enhance next-generation systems (passive and active) for superior automotive safety. The National Highway Traffic Safety Administration (NHTSA) Office of Vehicle Safety Research contributed its expertise to the process. R&D priorities were explored in four automotive areas (Interiors, Body/Exterior, Powertrain & Chassis, Lightweighting).

The Technology Integration Workshop Report provides a baseline for a more expansive safety road mapping effort examining Plastic and Composite Intensive Vehicles (PCIVs) that will reflect the consensus of leading technology developers, polymer and composite researchers, automotive safety engineers, designers, manufacturers, and government. This collaborative approach will also help industry, academia, and the government labs identify opportunities for new partnerships to pursue specific technologies or opportunities and will aid NHTSA in coordinating R&D and leveraging resources.

This paper explores the role of the Plastics Industry in facilitating development of Future Vehicle Architectures with enhanced active and passive systems for improved automotive safety worldwide.

INTRODUCTION

Plastics In Automotive Markets Today

Plastics encompass a wide variety of functional polymeric compounds that exhibit a vast range of desirable properties. They are durable, strong and lightweight. They can be made transparent, translucent or opaque; soft, flexible or hard in almost any shape, size or color. They can be heat-, chemical- and corrosion-resistant. They are excellent thermal and electrical insulators and also can be made electrically and thermally conductive. Because of plastics' versatility, they are extremely cost-effective in a wide variety of commercial applications including a broad range of uses in the transportation market.

Fisher 1

The use of both thermosets and thermoplastics in passenger vehicles has grown from about 30 kilograms per vehicle in 1970 to about 150 kilograms today. A midsize automobile manufactured in North America is about 10-12 percent plastics by weight. The material volume is much higher. Because plastics are versatile and lightweight, they make up approximately 50 percent of the material volume of new cars.

The Need for Fuel Efficiency and Reduction in Green House Gases

Leading experts say that the easiest and least expensive way to reduce the energy consumption and emissions of a vehicle is to reduce the weight of the vehicle. To achieve lightweight architectures, without compromising on rigidity, automakers have been researching the replacement of steel with plastics, composites, foams, aluminum and magnesium. The recycling and recovery of end-of-life vehicles, which involves recovery targets of 85%, are driving the auto industry to adopt lightweight materials technology to meet these recovery targets².

Weight reduction also offers a potentially cost-effective means to reduce fuel consumption and greenhouse gases from the transportation sector. It has been estimated that for every 10% reduction in the weight of the total vehicle, fuel economy improves by 5-7%. Thus for every kilogram of vehicle weight reduction, there is the potential to reduce carbon dioxide emissions by 20 kg.

Automakers Are Increasing Utilization of Lightweight Materials

Global emphasis is being placed on greenhouse gas reduction and fuel efficiency improvement in the transportation sector. Many vehicle manufacturers and suppliers are investing significantly in lightweight materials research and development and commercialization. Most companies are working toward the goal of increasing the use of lightweight materials to achieve more market penetration by manufacturing components and vehicle structures and designing new vehicle architectures that maximize the utilization of lightweight materials.

The American Chemistry Council (ACC) data indicate that currently:

- the average vehicle uses about 150 kg of plastics and plastic composites, versus 1163 kg (2559 lbs) of iron and steel³,
 - the automotive industry uses engineered polymer composites and plastics in a wide range
 of applications, as the second most common class of automotive materials after ferrous
 metals and alloys (cast iron, steel, nickel) which represent 68% by weight; other nonferrous metals used include copper, zinc, aluminum, magnesium, titanium, and their
 alloys.
 - the plastics contents of commercial vehicles comprises about 50% of all interior components, including safety subsystems, door and seat assemblies;
 - industry trends project a substantial increase in use of automotive plastics over the next
 two decades for reducing vehicle net weight, and for improving environmental impacts
 and fuel efficiency in response to consumer pressures, and to exploit the rapid advances
 in materials science and technology.

ACC Technology Integration Workshop

The Technology Integration Workshop held in November 2005 and resultant Report⁴ examining the role of plastics in future automotive safety represents a collaborative effort of 45 experts representing 29 organizations including plastics producers, auto manufacturers (OEMs), Tier suppliers, universities, and government resources. These experts provided a "snapshot in time" of the priorities for enhancing future automotive safety with plastics by specifying 130 industry challenges and more than 190 activities for overcoming them. This information was synthesized into the ACC Technology Integration Report. The Workshop was a collaborative effort involving the ACCPD and the National Highway Traffic Safety Administration of the U.S. Department of Transportation.

Fisher 2

Automotive Safety Today

Drivers are safer than they have ever been, in part because of safer cars, higher safety belt use and stronger safety laws.⁵ However, according to statistics, worldwide, the number of people killed in road traffic crashes each year is estimated to be almost 1.2 million.⁶ That's 3000 people killed on the world's roads every day. The number injured in road traffic accidents is estimated to be as high as 50 million – the combined population of five of the world's large cities. According to World Health Organization data, deaths from road traffic injuries account for around 25% of all deaths from injury.⁷ It is expected that, without efforts and new initiatives to tackle the causes of road traffic injuries and deaths, they will rise by some 65% between 200 and 2020⁸

In the United States more than 43,000 people die annually on roadways – the equivalent of an airplane crashing every day with nearly 120 people aboard – and fatality numbers have remained largely stagnant for the past two decades. In Japan there were 6,871 traffic accident deaths in 2005, the first time since 1956 that the number has fallen below 7,000. The number of casualties may be falling, but the number of accidents in Japan is higher than ever. According to the European Union, in 2000, road accidents killed over 40,000 people in the European Union and injured more than 1.7 million. The age group most affected is the 14-25 year olds, for whom road accidents are the primary cause of death. One person in three will be injured in an auto accident at some point in their lives. The directly measurable cost of road accidents is of the order of EUR 45 billion. Indirect costs (including physical and psychological damage suffered by victims and their families) are three to four times higher. The annual figure is estimated at EUR 160 Billion, equivalent to 2% of the European Union's Gross National Product.

As long as the number of highway deaths and crashes remains high, automotive producers will continue to seek innovative solutions that make people safer in their cars and trucks. The plastics industry has been an active partner in this process of innovation (see Figure 1) and remains committed to action. Globally, the World Health Organization and the United Nations are increasing their focus on automotive safety as a growing concern, particularly in developing nations with rapidly expanding economies, such as China and India where automobile use is growing rapidly. The ACC Technology Integration Report reflects the plastic industry's strong commitment to enhanced automotive safety and is aligned with both domestic and global needs.

Figure 1.

Overview of Use of Plastics to Enhance Safety in Today's Vehicles

Body and Exterior Interior Lightweighting · Composite fenders, truck bed · Seat belts · Light, energy-absorbing liners bumpers and instrument · Air bags, side air curtains panels . Foam in bumpers, front . Foam padding on pillars, doors, · Lighter hoods to lower center structures headers, trim, and dash of gravity Foam-filled structures · Plastic steering columns Shorter braking distances Plastic body panels, fascia . Inflatable and foam padding on glove frontal barriers, side barriers Improved maneuverability box and knee bolsters · Reflectors, mirrors, rear Flame retardants parking assist Lighted displays Window and windshield glazing Powertrain and Chassis Composite engine frames Plastic fuel lines Engine system components (e.g., crankshaft sensors) · Plastic cooling tubes with superior · Plastic housings for electronic impact resistance stability controls, automatic · Leak prevention (radiators, fuel braking systems, brake lines tanks and lines, battery cases Fuel tank heat shields

Run-flat tires

Technology Activities and Priorities in Four Key Areas

To meet the significant challenges associated with enhancing automotive safety, automotive and plastics producers, along with their suppliers, have identified a preliminary research agenda and set of priorities. The Technology Integration Workshop Report presents R&D priorities in four automotive areas that together capture the broad range of plastics applications in vehicles (see Figure 2). These four areas are Interiors, Bodies and Exteriors, Powertrain and Chassis Components, and Lightweighting:

- Interior Priorities for improving safety in the passenger compartment include making safety advances affordable through innovative design and more efficient manufacturing capabilities, designing for increased vehicle compatibility, accommodating an aging driver population, including more safety features in reduced package space, and enhancing safety belt designs.
- Body & Exterior From bumpers to body panels, laminated safety glass to rear parking assists, research activities must include energy management technologies that resist vehicle intrusion, impede roof crush, and reduce body and exterior weight without compromising safety performance.
- Powertrain & Chassis Research in this area focuses on components that generate and deliver power and include the frame and its working parts. R&D priorities include pursuing significant advancements in engineering and research capabilities for designing with plastics, exploring new ways to optimize safety and fuel efficiency, expanding predictive modeling capabilities for composite materials, and developing the new safety components that will be required for future alternative vehicles and powertrain options.

Figure 2.

Summary of Highest-Priority Research and Development Needed to Enhance Future Automotive Safety with Plastics

Body and Exterior Interior Lightweighting Enhance statistical analysis · Identify supply chain barriers Compose master plan for developing test standards, material to increase penetration of classifications, and modeling of plastic Further integrate safety into plastics in safety applications existing platforms (ongoing Decrease the cost and product cycles) · Improve side impact collision increase the availability of performance by addressing vehiclecarbon fiber parts for Define how regulations impact to-vehicle compatibility, aging structures plastics opportunities population needs, and other new and · Characterize plastic safety evolving side impact test procedures performance Standardize material performance specifications Powertrain and Chassis · Optimize safety and fuel efficiency · Define plastic opportunities as automobiles transition to alternative fuels · Increase continuing education on polymer and powertrains science and advanced engineering Improve predictive modeling capabilities for composites

Lightweighting – The transition to lightweight materials from conventional ones requires research activities that will increase the overall value of plastics in automobiles; develop new, high-

performance components that lower the center of gravity of a vehicle; improve crash avoidance and performance systems; and enhance pedestrian safety.

Common Themes and Top Priorities

At the Technology Integration Workshop, six important themes were repeatedly cited as central to the challenge of enhancing future automotive safety using plastics.

- 1. Improve Characterization and Predictive Modeling of Plastics Continuous improvement in predictive modeling of the crash performance of plastic components is vital to strengthening the position of plastics as a preferred automotive material. Automotive designers also require extensive materials characterization data for new plastics as they become available. Obtaining reliable, validated constitutive data may require a coordinated, industry-wide effort.
- 2. Develop Material Classifications, Test Standards, and Performance Specifications To encourage design engineers and original equipment manufacturers (OEMs) to choose plastics over competing materials, designers must be confident in the materials' ability to achieve required performance in the application. Because plastics are less familiar than metals to most design engineers, the plastics industry must benchmark performance and create material classifications to characterize their products. Afterward, OEM material performance specifications and test methods must be updated and expanded to reflect the unique properties and capabilities of these new materials.
- 3. Enhance Crash Performance with Improved Energy Management Managing the impact energy created during a crash and protecting occupants from absorbing too much of this energy is a fundamental part of vehicle safety. Advanced plastic components and systems in the interior, body and exterior, and powertrain systems are sought to allow automakers to manage crash energy in creative, more effective ways.
- 4. Uncover Plastic Opportunities under Evolving Active and Passive Safety Standards and Lightweighting Regulations Understanding technology needs for meeting evolving safety standards and lightweighting regulations addressing both crash worthiness and crash avoidance is a necessary foundation for planning future plastics research. The industry must better define plastics performance requirements of new safety standards and use with new integrated components, alternative fuel vehicles, powertrain options, and transportation infrastructure. Once these issues are determined, new opportunities for optimizing safety and lightweighting with plastics should be identified.
- 5. Accommodate Changing Demographics to Older Population As the population of older drivers increases, improved counter measures and crash performance systems will be needed to keep these passengers safe. Many older drivers have lower biomechanical tolerances and require special safety features to avoid injury. With targeted research, highly versatile plastics may enable important advances in safety features that are needed to protect the 65-and-older population.
- 6. Make Automotive Safety with Plastics Affordable Optimizing material selection for automotive safety components will require that plastics become more affordable, both as a material and as they enable efficiency gains throughout the vehicle manufacturing and assembly process. At the same time, the perception among automotive customers must be changed to appreciate the value of safety features enabled by plastics to increase their willingness to select those features.

CONCLUSIONS

By pursuing an initial collaborative technology agenda focused on R&D priorities most needed to enhance safety, the plastics industry and its key stakeholders have taken an important first step toward enhancing automotive safety with plastics. The Technology Integration Report provides a baseline for more expansive safety road mapping efforts that will reflect the consensus of leading technology developers, polymer and composite researchers, automotive safety engineers, designers, manufacturers, and

Fisher 5

government. This collaborative roadmapping approach is now underway in the United States and will also help industry, academia, and government labs identify opportunities for new partnerships to pursue specific technologies or opportunities. The roadmap will provide an integrating R&D agenda to align R&D efforts across public and private sectors and will aid NHTSA in coordinating R&D and leveraging resources. The aggregate impact will be increased efficiency and speed in developing successful automotive safety solutions—both active and passive.

In the Technology Integration Report, the plastics and automotive industries have articulated their wish to journey toward a future in which innovative materials will radically improve vehicle safety for passengers and pedestrians. Subsequent road mapping efforts will produce a clear set of directions defining an efficient and cost-effective route toward that future. To propel the plastics and automotive industries along this chosen route, collaborative partnerships among industry, universities, and government will generate the requisite power and momentum. The journey will entail rigorous challenges, yet the destination is worthwhile and careful planning and road mapping will ensure its success.

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